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# Commuter Exposure Model
# Description of Model Methodology and Code

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# COMMUTER EXPOSURE MODEL

## Description of Model Methodology and Code

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The commuter exposure modeling package consists of two documents. The User's Guide describes program execution and provides the user with the information needed to run the program. This document is a detailed description of the model methodlogy and code. This document is for users needing more detailed information about the model than is given in the User's Guide. It contains a detailed description of the model methodology and code that covers topics such as the definition of the modeling approach, traffic, emissions, and dispersion modeling, and commuter exposure statistics. A section describing and defining the symbols used in the computer code is also included. Detailed flowcharts of all of the model subroutines comprise another section. Finally, a discussion of the dimensions of arrays in the code and how to change dimensions is presented.

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## ABSTRACT

A topic of increasing concern to planning and regulatory agencies and to air quality modelers is the high air pollutant levels observed on roadways. Commuters, who drive during heavy demand periods and are exposed to perhaps the highest pollutant levels, are the group most affected. To investigate this problem, the U.S. EPA commissioned a study to develop a commuter exposure modeling methodology. The methodology has been designed to compute commuter exposure statistics through simulation of the traffic, vehicular emissions, and atmospheric dispersion of roadway-related air pollutants. A numerical computer-oriented code, based on the commuter exposure methodology, has been developed and implemented and is described in the User's Guide.

The commuter exposure modeling package consists of two programs that are to be run separately on the computer. The first program is an emissions preprocessor, which has been separated from the main model to facilitate updating of the model package when currently accepted methods for computing emissions factors are revised by EPA. The second program is the main portion of the commuter exposure model, which simulates traffic flow, computes the emissions rates resulting from the traffic (using the emission factors calculated by the preprocessor), simulates the dispersive effects of the atmosphere, and computes statistics describing commuter exposure.

The commuter exposure model is a tool that can be used to assess the pollutant levels to which commuters are exposed in various metropolitan areas. Since the model treats the spatial variation of exposure, regions

of the city in which commuters experience high exposures can be identified from model output. If a single commute pathway is of interest, that pathway can be examined in detail. The model facilitates study of exposure levels in relation to the percentage of the commuting population exposed. The length of time of exposure is also readily available for use in health effects studies. In addition to being useful for determining absolute exposure levels, the model can also assess the effects of implementing roadway improvements or transportation control measures.

The commuter exposure modeling package consists of two documents. The User's Guide describes program execution and provides the user with the information needed to run the program. This document is a detailed description of the model methodology and code.

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# SECTION 1

# INTRODUCTION

Two volumes have been prepared to describe the commuter exposure modeling package and its application. The first volume is a guide to program execution, intended to provide the user with the information needed to run the program. Information of a general nature about the model is included in the Introduction and other sections of this volume. The other volume is for users needing more detailed information about the model than is given in the first volume. It contains a detailed description of the model methodology and code that covers topics such as the definition of the modeling approach, traffic, emissions, and dispersion modeling, and commuter exposure statistics. A section describing and defining the symbols used in the computer code is also included. Detailed flowcharts of all of the model subroutines comprise another section of the guide. Finally, a discussion of the dimensions of arrays in the code and how to change dimensions is presented. A listing of the UNIVAC version of the code is included as microfiche in a back pocket of this volume.

# SECTION 2

# DETAILED DESCRIPTION OF MODEL METHODOLOGY

## 2.1 General

The commuter exposure modeling methodology simulates the exposure to which commuters are subject by considering individually and collectively three distinct subjects that affect exposure. These subjects are traffic flow, emissions, and atmospheric dispersion. The traffic characteristics that affect exposure are modeled, the resulting traffic parameters are translated into emission rates, and the dispersion of the emissions by the atmosphere are simulated.

To further clarify the structure of the model, a note should be made here regarding emissions simulation. Emission rates are computed from emission factors and traffic parameters. Since mobile source emission factor computation methodologies appear to be subject to frequent change, the commuter exposure modeling package was designed to operate as two programs. An emission factor computation program, called the emissions preprocessor (PREPRS), was created to facilitate incorporation of future emission factor methodology updates. The main model, CEMAP, reads the output of PREPRS (as well as other data) and simulates traffic flow, computes emission rates, and simulates dispersion. Even though the commuter exposure model consists of two programs, the modeling package is best described as a whole and is discussed as a whole in the remainder of this section.

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The commuter exposure model is capable of producing two kinds of statistics: (1) so-called short-term statistics, concerning a single commute: and (2) annual statistics, which describe average exposure or the frequency of occurrence of exposure throughout a year. In both the annual and short-term modes, the model allows the user to compute exposures for the "average" commuter on each of the pathways. (The "average" commuter is the driver who commutes mostly during the peak travel period.)

The differences in the way the model will compute annual and short-term exposures concern the consideration of the time period of the commute. Annual statistics require computations for each of various meteorological and traffic condition combinations, while short-term statistics apply to meteorological and traffic conditions occurring during a specific commute.

## 2.2 Definition of the Modeling Approach

The crux of the commuter exposure modeling program is defining the modeling area. This section describes a methodology for defining the modeling area in terms of the two important types of emission sources in a commuter exposure model: (1) line sources, or commuter pathways; and (2) nonpathway sources (the "background source effects") from the remaining roadway network.

### 2.2.1. Definition of Commute Pathways

The most critical aspect in defining the modeling area is choosing the appropriate commuter pathways. The commuter exposures that are

calculated and the statistics that are derived all depend directly on the pathways that are defined.

Fortunately, the major commuting pathways, or "commuting corridors," are well-defined and recognizable if one is familiar with the modeling area. Often, just the physical size of the roadway, or, more properly, its capacity, will identify it as a commute route. The commuting pathways are also corridors of development, fostered largely by the access to the urban core that the route provides.

For commuter exposure modeling to be a manageable problem, a reasonable number of major commuting routes or pathways must be defined. As presently dimensioned, the model allows for five major routes. The number of pathways will be a function of the size of the modeling area, but it should be less than 25. For larger urban areas, the model should be redimensioned, or multiple runs should be made (see Section 5). Those routes will generally have the highest number of vehicle miles traveled (VMT) by commuters.

Two types of roadways are candidates for commute pathways: expressways and arterials. A pathway may be composed of both. Commuting trips do not begin on the commute pathways as defined here, but rather, on local surface streets and "collectors." To handle the exposure during the approach to and departure from the pathway, minor pathways should be used that are representative of the travel to and from the route.

### 2.2.2. Non-Pathway Sources

Non-commute pathway pollutant emissions are treated on a grid square basis. The modeler will overlay the study area with a grid system, and in general the grid squares will have dimensions of 2 km by 2 km, although

variable grid sizes are allowed. The coordinate system used to define the grid must be consistent with the system used to define commuter pathway coordinates.

The primary street network is defined as those roadways carrying a major amount of the total vehicle miles traveled (VMT) on the entire roadway network of a metropolitan area. In general, the primary network can be considered to be those streets for which average daily traffic (ADT) values are available. For the commuter exposure model, the primary network should not include roadways that are commuter pathways.

Once the grid system is defined, the user must apportion the total VMT of primary network streets among the grid squares and input that information for the appropriate squares. In general, this procedure will be used to compute emissions from the primary network. However, the model allows the user to input an average daily emission rate for each grid square, in lieu of VMT. This option would be used when gridded emissions for the study area are readily available from another source or when the user has access to the projections generated by the Federal Highway Administration's (FHWA) battery of computer programs.

The secondary traffic network consists of all streets not in the primary network or commuter pathways. The approach used for assigning secondary traffic to grid squares assumes that the ratio of secondary traffic to grid squares assumes that the ratio of secondary traffic to primary traffic varies by locale (or by land use). For instance, virtually all of the streets in the Central Business District (CBD) are likely to be important enough to be included in the primary traffic network. Similarly, very little traffic in rural areas is likely to be

found off the major roadways. In residential and industrial areas, a large fraction of the total traffic may use secondary streets. The user estimates the ratio of secondary to primary traffic for each locale type. The locale type of each grid square or group of grid squares for which data are required also will be input. The model allots secondary network VMT on the grid squares in proportion to the product of the VMT on the primary network in that square and the ratio of the secondary to primary traffic associated with the locale type of the square.

If gridded emissions are input directly, as discussed previously secondary network emissions should be included in that inventory.

## 2.3 Traffic Modeling

Traffic modeling along commuter pathways requires the handling of two separate traffic flow regimes: uninterrupted flow and interrupted flow. Travel on expressways is generally uninterrupted, although during a backup, the flow can become severely constrained to the point of becoming "stop and go." Interrupted flow describes travel on arterials with traffic signals at the intersections.* The following discussion details those elements of the computer exposure model that describe the traffic flow.

### 2.3.1. Uninterrupted Flow

The characteristics of uninterrupted flow can be obtained from two parameters, demand volume (v) and free-flow capacity (c) of the road segment. Both are required inputs to the model. Seasonal adjustment factors

* Intersections that have stop signs are not considered since they will not be present for the main traffic flow on an arterial, commuter pathway.

are also needed to define how the AADT changes with season (winter includes December-February, spring includes March-May, etc.).

The commuter exposure model allows the input of hourly volumes directly, ADT, AADT, and the appropriate correction factors. Typical values of the correction factors are built into the model as default parameters. The user of the model tells the model the form of data that are being input and also has default correction factors available if necessary.

The capacity of a roadway is defined in the Highway Capacity Manual[1] as "the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a roadway in one direction (or in both directions for a two-lane or a three-land highway) during a given time period under prevailing roadway and traffic conditions." Usually, capacity pertains to a one-hour period. Capacity will vary along segments of a commute pathway because of physical characteristics, the makeup of the traffic, weather conditions, accidents, and so forth.

For the commuter exposure model, a default capacity is provided for each type of roadway. If the local transportation agency can provide better estimates, such as from field study results, those data should be used.

Once volume and capacity are known for a freeway or expressway, the speed at which traffic moves may be determined. Figure 1 shows the relationships between the ratio of volume to capacity and the operating speed in one direction of travel and under uninterrupted flow conditions for freeways and expressways. Similar curves exist for arterials. Equations have been fitted to those curves and are functions in the model. Given

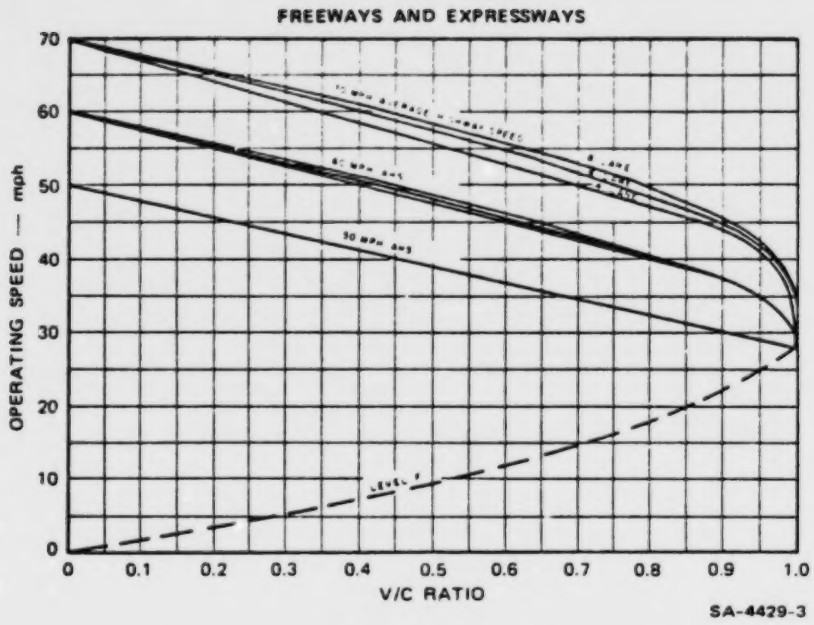


FIGURE 1 RELATIONSHIPS BETWEEN V/C RATIO AND OPERATING SPEED, IN ONE DIRECTION OF TRAVEL, ON FREEWAYS AND EXPRESSWAYS, UNDER UNINTERRUPTED FLOW CONDITIONS

volume and capacity, the operating speed is then calculated for use in calculations of emissions and travel or exposure time.

The methodology described so far applies to uninterrupted flow on freeways and expressways. It is possible for the flow to become constrained to the point of being stop-and-go on expressways and freeways, either because of a particularly high demand volume or because capacity is reduced for some reason. The following discussion presents the method used in the commuter exposure model for calculating the number of vehicles that would be influenced by a traffic backup when volume exceeds capacity. The method for calculating average exposure time is also given.

When the demand volume exceeds capacity, a backup builds up in the congested area at a rate equal to demand minus capacity:

$$\frac{dn}{dt} = q-s \qquad q > s$$

n = size of backup (vehicles)

q = demand volume over a suitable averaging time, (vehicles/sec)

s = capacity of the particular section of the road on which the backup occurs (vehicles/sec)

t = time (sec)

The backup increases and reaches a size, N, at some time, $t'$, measured from the time that the backup begins ($q > s$), when $q = s$:

$$N = (q-s)t'.$$

The total number of vehicles affected by congestion includes N plus those entering the backup after capacity exceeds demand ($s > q$), but before the backup dissipates. The backup is relieved at some time, $t''$, measured from the time when $q = s$; ($t'' = t-t'$), satisfying

$$st'' - N - qt'' = 0$$

$$t'' = \frac{N}{s-q} \qquad s > q.$$

The total number of vehicles affected is

$$\hat{N} = N + qt''$$

$$= N + \frac{qN}{s-q} = \frac{sN - qN + qN}{s-q}$$

$$\hat{N} = \frac{N}{1-q/s}.$$

Note that the numerator is evaluated for the time that $q > s$, while the denominator is evaluated during $s > q$. Note also that q is the demand volume over a suitable averaging time that is representative of the transiency of the backup.

The "delay," or time spent traversing the backup, is a function of the length of the backup and the average travel speed:

$$D = D(n,v).$$

Assuming each vehicle occupies a constant k meters,

$$D = \frac{kn}{v},$$

and assuming that the average speed is constant, then the change in delay to vehicles entering the backup at different times is

$$dD = \frac{kn}{v}\, dn,$$

and the total delay for all vehicles is

$$\int dD = \int \frac{kn}{v}\, dn.$$

Calling the total delay D, we have

$$D = \int_0^N \frac{kn}{v}\, dn.$$

For $q > s$, $n = (q-s)t$ and $dn = d\left[(q-s)t\right] = (q-s)dt$, since q and s are also assumed constant. Then

$$D = \int_0^T \frac{k(q-s)^2 t\, dt}{v} = \frac{k(q-s)^2 t^2}{2v}\Bigg|_0^T$$

where $T = N/(q-s)$. The average delay is D/N, or $D/\int_0^T (q-s)dt$

$$D_{avg} = \frac{\dfrac{k(q-s)^2 t^2}{2v}\Big|_0^T}{(q-s)t\Big|_0^T} = \frac{k(q-s)t}{2v}\Bigg|_0^T$$

$$= \frac{k(q-s)T}{2v}$$

$$\text{or } \frac{kN}{2v}.$$

The average delay when s > q is calculated in the same manner. In this case, the number of vehicles in the backup is

$$n = N - (s-q)t$$

$$\text{and } dn = -(s-q)dt.$$

Then

$$D = \int_{N}^{0} \frac{kn}{v}\, dn$$

$$= \int_{T'}^{0} \frac{k\left[N-(s-q)t\right](s-q)dt}{v}$$

and the total delay can be calculated from

$$D = -\left.\frac{kN(s-q)t}{v}\right|_{T''}^{0} + \left.\frac{k(s-q)^2t^2}{2v}\right|_{T''}^{0}$$

where T" is the time for the backup to dissipate. Since T" equals N/(s-q), the total delay for vehicles arriving when s > q is

$$D = \frac{kN^2}{v} - \frac{kN^2}{2v}$$

$$= \frac{kN^2}{2v}$$

The average delay per vehicle is

$$D_{avg} = \frac{kN^2}{2v(\hat{N}-N)}.$$

The total delay when q > s equals the total delay when s > q. The average delay for all vehicles is then

$$D_{avg} \text{ (all vehicles)} = \left(\frac{kN^2}{2v} + \frac{kN^2}{2v}\right) \div \hat{N}$$

$$= \frac{kN^2}{v\hat{N}}$$

As an example, consider the data below, giving five-minute demand volumes on a roadway with a capacity of 2000 vehicles/hr, 167 vehicles/five minutes, or .55 veh/sec:

| Five-Minute Increment | Demand Volume |
|---|---|
| 1 | 167 |
| 2 | 200 |
| 3 | 200 |
| 4 | 210 |
| 5 | 180 |
| 6 | 190 |
| 7 | 180 |
| 8 | 150 |
| 9 | 110 |
| 10 | 100 |

In increment 1, demand equals capacity, and no backup occurs. In increments 2-7, demand exceeds capacity. The average demand is 1160 vehicles/1800 sec, or .64 veh/sec.

The number of vehicles backed up during this period is then

$$N = (q - s)t'$$
$$= (.64 - .55)\ 1800$$
$$= 160 \text{ vehicles.}$$

During the next 15 minutes, the additional vehicles backed up equals

$$\frac{qN}{s-q} = \frac{(.40)(160)}{.55 - .40} = 411 \text{ vehicles.}$$

The total is

$$160 + 411 = 571 \text{ vehicles.}$$

The time for the backup to clear up is given by $t'' = \frac{N}{s-q}$

$$= \frac{160}{.55 - .40} = 1029 \text{ seconds} = 17.1 \text{ minutes.}$$

Assuming that vehicles in the congested area are able to maintain an average speed of 20 mi/hr, and assuming a time headway of 1.8 sec, each vehicle "occupies" 16 meters. The time for the 160th vehicle to pass through the congested area is

$$\frac{(160 \text{ vehicles})(16\text{m/vehicle})}{(20\text{mi/hr})(0.447\text{m/sec/mi/hr})} = 286 \text{ sec.}$$

$$= 4 \text{ min, } 46 \text{ sec.}$$

Assuming a 2-second headway yields

$$\frac{(160)(18\text{m/vehicle})}{(20)(0.447)} = 5 \text{ min, } 22 \text{ sec.}$$

This example shows that, first of all, the calculation of the total queue length produces a conservative estimate. During the last three five-minute increments, 360 vehicles approach the congested area, while the calculation indicates that 411 vehicles enter the backup. Also, the time for the congestion to break up is presented as 45 minutes, while the calculated time is 30 + 17.1 minutes, or 47.1 minutes. This extended time and the conservative calculation of the number of vehicles affected are directly related.

Figure 2 indicates that the maximum time for a vehicle to pass through the congested area is just under five minutes. The calculated values of 4.8 and 5.4 minutes agree reasonable well with this time.

The "delay", or the time for vehicles to traverse the backup is, for $q > s$,

$$D = \frac{8(.64 - .55)^2 1800^2}{(20)(.44704)} \quad *$$

$$= 22906 \text{ vehicle sec}$$

or 143.2 sec average per vehicle;

for $s > q$

$$D = \frac{8(.55 - .40)^2 1029^2}{(20)(.44704)} \quad *$$

$$= 22906 \text{ vehicle sec}$$

or 55.7 sec/average vehicle

The average over the life of the backup is

$$\frac{2(22906)}{(160 + 411)} = 80.23 \text{ sec average per vehicle}$$

* Some of the numbers in this equation have been rounded.

The equations presented above for backup conditions occurring when demand volume exceeds capacity are included in the commuter exposure model. That is important for modeling worst-case exposures, as well as for providing a more realistic indication of overall commuter exposure. The example calculations apply to one lane of traffic; a four-lane expressway with similar conditions in each lane would have a backup involving 2,284 vehicles.

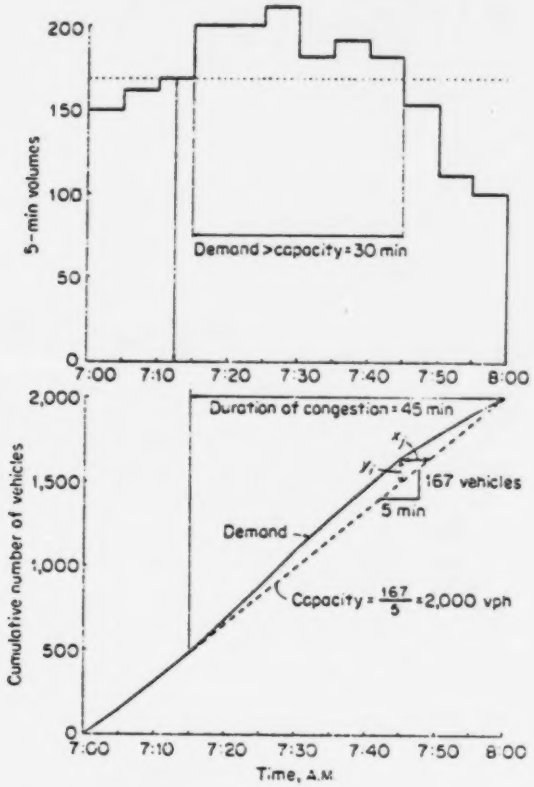


FIGURE 2 RELATION BETWEEN DEMAND, CAPACITY, AND CONGESTION

2.3.2. Interrupted Flow

Interrupted flow pertains to traffic conditions when movement is routinely stopped, or interrupted, for a finite period of time. For the purposes of the commuter exposure model, only two causes of interrupted

flow need be considered: signalized intersections and toll booths. At those two locations of interrupted flow, traffic goes through mode changes from cruise to deceleration, idle, acceleration, and back to cruise. Emissions, and hence concentrations, and times of exposure are influenced by those mode changes.

Comparisons of emissions estimates made using the Modal Analysis Model[3] and the FTP methodology[4] have shown good agreement except at low average route speeds. That is to be expected because as the average route speed increases, more driving time is spent at or near the average route speed, and there are fewer changes of driving mode. At lower speeds, however, there is an increasing array of mode and speed combinations that can produce the same average speed, and the FTP methodology does not fully account for that. As a result, the commuter exposure model includes traffic modeling capabilities for both average route speed and mode changes for interrupted flow conditions. The average route speed methodology is used outside of the CBD, while the modal methodology is used inside of the CBD. The reason for this choice is that speeds are likely to be lowest and mode changes most frequent within the CBD, and the difference among emission estimates most pronounced. Although the use of the average route speed/FTP methodology for interrupted flow conditions outside of the CBD does not provide the spatial detail that the modal treatment can give, that is not crucial for the commuter exposure model, because exposure is time-integrated along the pathway. Using an average route speed temporally smooths emissions instead of concentrations.

A more thorough analysis is warranted for CBD pathway segments. Calculations must be made of driving mode changes, the proportion of vehicles changing modes, and the length of time spent in the different modes. Basically, that requires a calculation of queue lengths and delay at intersections. The parameters required are demand volume, capacity, and the traffic signal parameters of cycle length and the length of the green phase. Queue length and delay data can then be used to calculate modal emissions.

Ideally, capacity, volume, and signal parameters will be obtained from the local agency and input directly to the model. However, given the demand volumes on the intersection approaches, the geometry of the intersection, and the composition of the traffic as described below, first the capacity and then the signal parameters (and then queue length and delay) can be calculated. The following discussion explains how this is done. The commuter exposure model calls on the user to supply capacity, but has the default option of performing the remaining calculations of signal parameters.

Any at-grade intersection approach has a capacity that represents the maximum number of vehicles that can be accommodated, given the particular geometry, environment, and traffic characteristics and controls. The capacity service volume of an intersection approach is the maximum number of vehicles that can pass through the intersection during one hour of green time. The number of vehicles that can clear the intersection from an approach during one hour of elapsed time can be calculated by multiplying the fraction of the total cycle time that the signal is green by the capacity service volume.

The approach capacity, C, is determined by multiplying the capacity service volume by the G/Cy ratio for the approach. The green phase time, G, and cycle time, Cy, are determined by Webster's "Traffic Signal Settings".[5] Webster's equations provide enough cycle time for the vehicle demand volume to proceed through the intersection; however, the user must ensure that G for each phase is long enough for pedestrian crossings. To determine Webster's optimum cycle length, the critical or maximum volume to capacity service volumes must be determined for each phase. The maximum volume to capacity service volume for phase i is written as

$$\underset{i}{\text{Max}} \left[ V_{i,j} / Cs_{i,j} \right]$$

and refers to those V/Cs ratios for approaches or lanes of approaches on which traffic moves on phase i. For example, if approaches 1 (i=1) and 3 (i=3) to an intersection move on phase 1 (j=1) of a signal, then

$$\underset{i}{\text{Max}} \left[ V_{i,j} / Cs_{i,j} \right] = \text{Max} \left[ V_{1,1} / Cs_{1,1}, \; V_{3,1} / Cs_{3,1} \right] ,$$

and if phase 1 above is a left-turn phase, and phase 2 controls through and right-turning traffic on approaches 1 and 3, then

$$\underset{i}{\text{Max}} \left[ V_{i,j} / Cs_{i,j} \right] = \text{Max} \left[ V_{1,2} / Cs_{1,2}, \; V_{3,2} / Cs_{3,2} \right] .$$

In the above example, $V_{1,1}$ is the left-turn volume demand for Approach 1 and $Cs_{1,1}$ is the capacity service volume for left-turning traffic from Approach 1; similarly, $V_{1,2}$ is the through and right-turning volume demand for Approach 1 and and $Cs_{1,2}$ is the capacity service volume for through and right-turning traffic on Approach 1. The optimum signal cycle length is determined using the following equation:

$$Cy = \frac{(9 \; Np + 5)}{1 - \underset{\text{all } j}{\Sigma} \; \underset{i}{\text{Max}} \left[ V_{i,j} / Cs_{i,j} \right]}$$

where

Np = the number of amber intervals per signal cycle during which there is no simultaneous green phase.

9 = a constant representing a weighted lost time in which three seconds of amber time and three seconds of start-up time are assumed.

$V_{i,j}$ = the volume on the $i^{th}$ approach that moves during the $j^{th}$ signal green phase.

$Cs_{i,j}$ = the capacity per hour of green to vehicles on the $i^{th}$ approach moving during the $j^{th}$ signal phase.

The green phase length is a fraction of the signal cycle time minus the total amber time. A three-second amber time is assumed for all green phases. (A three-second amber time is usually adequate for roadways with a speed limit less than or equal to 35 mi/hr. A four-second amber time is applicable for speeds of 35 to 50 mi/hr, and a five-second amber time is applicable beyond 50 mi/hr.) The green phase length of phase j is given by the following equation:

$$G_j = Cy \frac{\underset{i}{\text{Max}} \left[V_{i,j}/Cs_{i,j}\right]}{\underset{\text{all } j}{\Sigma} \underset{i}{\text{Max}} \left[V_{i,j}/Cs_{i,j}\right]} - 3$$

where

- $\underset{i}{\text{Max}} \left[V_{i,j}/Cs_{i,j}\right]$ is the maximum V/Cs ratio on all approaches i moving on green phase j.
- 3 is an assumed 3-sec amber time
- $\underset{\text{all } j}{\Sigma} \left[V_{i,j}/Cs_{i,j}\right]$ is the sum of the V/Cs ratios that control the green phase durations.

The approach capacity is found by multiplying the approach capacity service volume by the appropriate green to cycle ratio and summing for all applicable phases. Since an approach is considered to be one direction of flow into an intersection, separate left-turning, through,

and right-turning signal phases affecting one approach should have their capacities added together to determine the total capacity of an approach. The capacity of an approach is given as follows:

$$C_i = \sum_j Cs_{i,j} \, Gj/Cy$$

where j are those green signal phases that allow traffic to move on intersection approach i. Two green signal phases representing opposing approaches are used in the commuter exposure model.

Once capacity, volume, and the signal parameters are known, the proportion of vehicles that stop for a signal is given by

$$P = \frac{1-G/Cy}{1-V/Cs}$$

where G = length of the green phase

Cy = signal cycle length

V = hourly demand volume

Cs = capacity service volume per hour of green.

The number (N) of vehicles subject to queueing delay is:

$$N = \frac{P \; V \; Cy}{3600}$$

while the maximum length of the queue (Lq, m) is:

$$Lq = 8N/M$$

where 8 is the distance (meters) occupied by each queued vehicle and M is the number of lanes in the approach. On the average, a stopped vehicle waits one-half the length of the red phase, so the average delay to those vehicles is

$$D = 0.5 \; (Cy-G).$$

For toll booths, the methodology is different because all vehicles must stop and wait to be served. The average number of vehicles waiting to leave a toll booth is computed from classical queueing theory as

$$N = \frac{V}{C-V}.$$

The queue length in meters is

$$Lq = \frac{8N}{M} .$$

The average delay for vehicles at a toll booth is the queue length (vehicles) multiplied by the average service rate, or inverse of capacity:

$$D = \frac{3600\ N}{C} .$$

Note that this applies to all vehicles because all must stop.

## 2.4 Emissions Modeling

The model user has the option of defining emission rates for each pathway segment and grid square directly or of having the model compute the emission rates. If emissions are to be computed, two types of emissions treatments are required of the commuter exposure model: a treatment based on the average route speed, and one that considers the effects of driving mode changes on emissions. The first treatment is given by the familiar FTP procedure.[4] The second treatment will use the "Automobile Exhause Emission Modal Analysis Model,"[3] or modal model. Emissions modeling along pathways requires both treatments; FTP-based emissions estimates are suitable for non-pathway sources. In its present version the model computes only CO emissions, although the capability of computing emissions for other pollutants can be retrieved by modifying the computer code.

### 2.4.1 Emissions on Pathways

All emission factors are computed by the emissions preprocessor. Emission rate computations are made by the main model. FTP emission factors are used for pathway segments that are freeways, expressways, or arterials outside the CBD. The FTP methodology requires the following input parameters as a minimum: altitude, state (California or other), calendar year, vehicle model year mix, and vehicle type mix, although national average data vehicle mix data may be used as a default.

The basic FTP emission factors assume an average route speed of 19.6 mi/hr, an ambient temperature of about 75°F, and 20 percent cold-starting, 27 percent hot-starting, and 53 percent hot-transient vehicles. When conditions depart from these assumed values, a combined speed-temperature-cold start and air-conditioning correction factor is applied. All other FTP correction factors (e.g., trailer towing) are assumed to have a value of unity.

For the purpose of the commuter exposure model, it is assumed that no vehicles are operating in the cold-start mode while they are on freeways, expressways, or pathways outside of the CBD. While cold-start emissions might affect background concentrations by their impact on network-wide emissions, travel to the pathways in the morning is assumed to take place on roadways having relatively low on-roadway concentrations. In the evening, vehicles are assumed to be warmed up by the time they leave the CBD or enter a freeway or expressway.

When there are no cold-starting vehicles, the combined cold-start-temperature-speed correction factor loses its temperature dependence and becomes a function of speed only. However, the air-conditioning

correction factor will differ for morning and evening commutes. To reduce repetitive calculations, the emissions preprocessor computes emission factors for speeds of 10 to 60 mi/hr in increments of 5 mi/hr; estimates of speed are rounded to the earnest 5 mi/hr. That is well within the accuracy of the speed estimation procedures. For the annual mode of model operation, 11 FTP emission factors, corresponding to 11 speeds, are computed for pathways for the morning commute and 11 factors are computed for the evening commute. For the short-term mode, 11 factors corresponding to the commute of interest are computed. These factors are written on a file by the emisisons preprocessor, to be read by the main model.

The mechanics of emission rate computations in the main model proceeds in the following way. For each non-CBD, freeway, or expressway segment of a pathway, the following equation is used to compute emissions:

$$Q = \frac{EV}{(3600)(1609)}$$

where

Q = emissions rate, g/m/sec

E = FTP emission density, g/vehicle-mi.

V = demand volume, vehicles/hr

3600 = sec/hr

1609 = m/mi

The emission density, E, is to be chosen from the previously computed table, according to average route speed. To compute the average emission rate over a segment having congested flow, it is convenient to break the emissions into two components: (1) those occurring during normal flow, E, and (2) the excess over normal flow emissions that occurs during congested flow, E'-E, where E' represents the emissions during congested flow. The component of total emissions due to uncongested flow is given by the above expression for Q, with E chosen according to the average route speed on the uncongested portion of the segment. The component due to congested flow is

$$Q' = \frac{(E'-E)\,\hat{N}}{1609\,\hat{T}}\ , \quad \text{g/m/sec}$$

where E' corresponds to an average route speed of 20 mi/hr and $\hat{T}$ is the duration (sec) of the backup. The average emission rate over the pathway segment is calculated as

$$Q_{avg} = Q + \frac{\hat{T}\ Lq\ Q'}{3600\ L}\ ,\ g/m/sec$$

where L = segment length, mi

Lq = backup length, mi

= 0.01 N.

Substituting for Q and Q' and reducing, the expression for $Q_{avg}$ is

$$Q_{avg} = \frac{EV + (E'-E)\hat{N}\ Lq/L}{(1609)(3600)}\ .$$

In the annual mode, the model will compute two emission rates, using the volumes of the morning and evening commutes. In the short-term mode, the model will compute only one emission rate, appropriate to the volume of the hour during which the "average" commuter travels the segment.

Travel on arterials within the CBD is characterized by interrupted flow and low speeds, and a modal emissions treatment should be used. This was available through an adaptation of EPA's modal model.

The modal model determines an instantaneous emission rate, e(t), which is a function of vehicle speed, v, and acceleration, a. Since speed and acceleration are functions of time, the emission rate function can be expressed as

$$\dot{e}(t) = \dot{e}\left[v(t),\ a(t)\right]\ .$$

Acceleration to or from a given speed is assumed to be a perturbation to the steady-state emission rate, and two equations are used to describe the emission rate:

$$\dot{e}_A(v,a) = b_1 + b_2v + b_3a + b_4av + b_5v^2 + b_6a^2 + b_7av^2 + b_8a^2v + b_9a^2v^2 \quad (A)$$

and

$$\dot{e}_s(v,o) = b_{10} + b_{11}v + b_{12}v^2, \quad (B)$$

where the first equation describes the non-zero acceleration emission rate and the second describes emission rates for steady speeds. Note that the idle emission rate equals the coefficient $b_{10}$.

Inputs to the modal model include calendar year, vehicle model year mix for various locations (low or high altitude, California or outside California) and second-by-second speed data for the driving sequence being modeled. The two preceding equations are solved for each second, the results are taken as one-second integrated emissions, and the model output is the total emissions over the driving sequence. Eighteen vehicle groups can be included in the vehicle mix; deterioration as a function of calendar year is included in the emission calculations. The 18 groups are listed in Table 1.

Second-by-second speed profiles are inconvenient input data for roadway air-quality modeling. As a result, the basic modal model has been modified to accept and calculate more appropriate parameters. Patterson[6] modified the model to accept inital and target speeds and acceleration or deceleration as inputs, and to calculate an emission density (g/m) over successive eight-meter lengths of roadway. The distance of eight meters was chosen for convenience because it is the average distance occupied by a queued vehicle. Time was entered from traffic modeling data. Sandys[7] used the median speed during deceleration or acceleration as the basis for a modal emission calculation that was assumed to be an average value for the mode. Inputs were speed, and acceleration or deceleration. In other work, Patterson[8] computed emissions during acceleration and deceleration in a one-step process by integrating the instantaneous emission rate over time. That approach yields almost the same result as using the median speed, but it recognizes the nonlinear speed dependence of the fifth, seventh, and ninth terms of the instantaneous emission rate equations.

Modeling the effects of modal emissions is facilitated through the introduction of the concept of excess emissions. Excess emissions are those that occur over and above those that would have occurred had the vehicle not stopped. The acceleration or deceleration parts of excess emissions are then the difference between the acceleration or deceleration emissions given by equation (A) and the cruise emissions calculated by equation (B). Similarly, the idle part of excess emissions is the difference between the idle emissions, given by the coefficient $b_{10}$ of equation (B), and the cruise emissions. The emissions during acceleration or deceleration

Table 1

VEHICLE GROUP DESIGNATIONS

| | | |
|---|---|---|
| Group | 1 | - 1957-1967 Denver |
| Group | 2 | - 1957-1967 low-altitude cities (non-California 1966, 1967) |
| Group | 3 | - 1966, 1967 California |
| Group | 4 | - 1968 low altitude cities (49-state) |
| Group | 5 | - 1969 low altitude cities (49-state) |
| Group | 6 | - 1970 low altitude cities (49-state) |
| Group | 7 | - 1971 low altitude cities (49-state) |
| Group | 8 | - 1968 Denver |
| Group | 9 | - 1969 Denver |
| Group | 10 | - 1970 Denver |
| Group | 11 | - 1971 Denver |
| Group | 12 | - 1972 Denver |
| Group | 13 | - 1973, 1974 Denver |
| Group | 14 | - 1972 California |
| Group | 15 | - 1973, 1974 California |
| Group | 16 | - 1972 low-altitude cities (49-state) |
| Group | 17 | - 1973, 1974 low-altitude cities (49-state) |
| Group | 18 | - 1975 low-altitude cities (49-state) |

are found by assuming that acceleration is constant, converting speed to a function of time, $v = at$, substituting in equation (A), and integrating over the time, T, to come to a stop or to reach cruise speed:

$$\text{Total acceleration or deceleration emissions} = \int_0^T \dot{e}_A(v(t),a)dt, \text{ grams.}$$

The cruise emissions that would have occurred had the vehicle not stopped are found by integrating $\dot{e}_s$ over ½ T:

$$\text{Cruise emissions} = \int_0^{T/2} \dot{e}_s(v(t),o)dt, \text{ grams.}$$

For one vehicle, the acceleration and deceleration parts of the excess emissions, $E_{AD}$, are, assuming acceleration equals deceleration:

$$E_{AD} = \int_0^T \dot{e}_A(v(t),a)dt + \int_0^T \dot{e}_A(v(t),-a)dt - 2\int_0^{T/2} \dot{e}_s(v(t),o)dt$$

Idle emissions must be added to $E_{AD}$ to arrive at the total excess emissions. The values for total excess emissions, $E_E$, in units of g/m/sec, are calculated as

$$E_E = \left( \frac{E_{AD}\ N}{Cy} + \frac{b_{10}\ DVP}{3600} \right) / Lq .$$

The cruise emissions component may be calculated by

$$E_C = \frac{\dot{e}_s\ V/3600}{v\ 1609.344/3600} \text{ g/m/sec}$$

where 1609.344 is the number of meters in a mile. For calculating concentrations, note that the total excess emissions, $E_E$, will be averaged over the queue length. The cruise emissions component occurs at all points along the roadway.

Operationally, the values of $E_{AD}$ and $E_C$ are calculated once in the emissions preprocessor and stored for initial and target speeds of 0 to 30 mi/hr in increments of 5 mi/hr. Acceleration and deceleration may be taken to be a constant 2.5 mi/hr/sec, based on work by Patterson[6] and Ludwig[9]. The initial speed for deceleration and the target speed for

acceleration will generally be the same across an intersection. If the two speeds differ, the lower speed is chosen to provide a conservative estimate when choosing a value for $E_{AD}$ based on speed.

Once emissions are calculated with the modal treatment in the pre-processor, they are averaged for each link or pathway segment in the emission rate computation module of the main model. To do this, the total excess emissions (excess per vehicle times the number stopping), $E_E$, are multiplied by the queue length, the cruise emissions are multiplied by the link length and the results are added and divided by the length of the link. This can be expressed as:

$$E_{avg} = \frac{E_E Lq + E_C x}{x}$$

where $E_{avg}$ = average emissions on link, g/m/sec

Lq = queue length, mi

x = link length, mi

$E_E$ = excess emissions per stopping vehicle, g/m/sec

$E_c$ = cruise emissions per vehicle, g/m/sec.

The discussion on FTP emissions estimates mentioned the exclusion of cold-start (and therefore temperature) corrections, because vehicles were assumed to be warmed up on a freeway, expressway, and non-CBD arterial segments of the pathways. In the evening, vehicles leaving the CBD cannot be assumed to be warmed up, and correction factors must be applied to the emissions estimates. The EPA methodology for correcting modal emissions for cold-starts and temperature involves the use of the FTP combined speed-temperature-cold-start correction factors. A modal correction factor is found by taking the ratios of the FTP combined correction factors. The numerator of the ratio is the FTP correction factor computed for the temperature and percentages of cold-start, hot-start, and hot-transient vehicles of interest and the roadway's average route speed. The

denominator of the ratio is the FTP correction factor for the same temperature and average route speed, but with completely warmed-up vehicles. The commuter exposure model computes this ratio for the input percentage of cold-starting vehicles. If the model is in the annual mode, the percentage of cold-starts is for the evening commute in the CBD, and an annual average temperature for the evening commute period. If the model is in the short-term mode, the percentage refers to the single commute being analyzed, and the average temperature of that commute.

For both modes of operation, the temperature/cold start correction factor is computed for speeds from 5 to 30 mi/hr in increments of 5 mi/hr by the emissions preprocessor. Then this correction factor, along with the appropriate FTP air conditioning correction factor, is applied to the modal excess and cruise emission factors calculated in the emissions preprocessor for each of the six average route speeds.

Another factor that must be considered for the modal model is a correction factor to account for non-light-duty vehicles. Because the modal methodology considers only light-duty vehicles, a factor that accounts for the vehicle type mix input to the model must be included. The correction factor is found by computing the ratio of the composite emission factor to the light-duty vehicle emissions factor for the input vehicle type mix temperature and cold start percentages for each of the six speeds. These correction factors are applied to the appropriate excess and cruise emission factors in the preprocessor.

The user has the option of inputing emission rates for each pathway segment directly, and if that option is exercised, the emissions module described above is bypassed. The direct input option may be particularly useful if a pollutant other than carbon monoxide is to be modeled.

### 2.4.2. Non-Pathway Emissions

Unless non-pathway emissions are input directly, emission factors from primary and secondary traffic in the grid squares are computed with the use of the latest FTP methodology in the emissions preprocessor. As mentioned under the discussion of pathway emissions, the methodology requires the following parameters:

- Calendar year
- Model year mix
- Vehicle type mix
- Average route speed
- Ambient temperature
- Percentage of catalyst and non-catalyst cold-starting, and catalyst hot-starting vehicles.
- Percentage of vehicles equipped with air-conditioning having air-conditioner running

The calendar year, the vehicle type mix, and the model year mix are input and fixed over the time period over which exposures are to be computed (up to one year). For non-pathway emissions, the standard FTP average route speed of 19.6 mi/hr is assumed in computing the combined speed-temperature-cold start correction factor. All other correction factors in the FTP methodology will be assumed to be unity for non-pathway sources, except the air conditioning correction factor.

When the commuter exposure model is in the annual mode, average annual morning and evening temperatures are used in the combined correction factor. Percentages of catalyst and non-catalyst cold-starting, and catalyst hot-starting, vehicles, varying according to locale are

input to the preprocessor and used in computing the factors. The emissions preprocessor computes 10 emission factors: for the morning commute's temperature and five cold-start/hot-start percentages (for the five locale types); and for the evening commute's temperature and five cold-start/hot-start percentages. The main model then computes morning and evening emission rates for each grid square by: (1) choosing the emission factor appropriate to the time of day and the grid square's locale type from the emission factors computed by the preprocessor, (2) multiplying the vactor by the VMT of the grid square, (3) multiplying the total by the percentage of the daily VMT appropriate to the average hour of the commute, and (4) dividing the total by the area of the grid square.

When the model is in the short-term mode, the average temperature and cold-start/hot-start percentages (for each of the five locale types) specific to the commute being analyzed are input to the model. The emissions preprocessor computes an emission factor for each locale type, and the main model computes an emission rate for each grid square in the same manner as described previously for the annual model of operation.

When daily gridded emissions are input directly, they must be converted to emission rates for the average commute hour. In the annual mode, percentages of daily traffic appropriate to the average morning and average evening commute hour are applied to the daily rate for each square, in order to produce gridded morning and evening emissions. For the short-term mode, the percentage of daily traffic appropriate to the average hour of the commute being analyzed are applied to each gridded emission rate.

## 2.5 Dispersion Modeling

### 2.5.1 Dispersion of Pathway Emissions

#### 2.5.1.1. Non-Street Canyons

For the purpose of computing the dispersion of vehicular emissions on commute pathways, limited-access and nonlimited-access pathway segments are distinguished from segments located in a street canyon.

The dispersion of pollutants emitted by vehicles on both limited-access and nonlimited-access roadways is computed using a technique taken from the CALINE3 dispersion model.[10] In this formulation individual roadway links are divided into a series of elements that each contribute to the concentration at a receptor. As the distance between element and receptor increases, the size of the element increases as a function of wind-roadway angle to gain efficiency in computation. The concentrations resulting from the individual elements are summed to form a total concentration estimate at a receptor.

Each element is modeled as an "equivalent" finite line source that is centered at the midpoint of the element and positioned normal to the wind direction vector. The length of the equivalent line is a function of element size and wind/roadway angle. Emissions are assumed to disperse in a Gaussian distribution downwind of the element. To arrive at an equitable distribution of emissions, each element is divided into five sub-elements whose source strengths assume a step-function form.

The Gaussian crosswind finite line source equation is approximated in the formulation by the following equation:

$$X = \frac{1}{\sqrt{2\pi}\,U} * \sum_{i=1}^{n} \left\{ \frac{2}{SGZ_i} * \sum_{k=-CNT}^{CNT} \left[ \exp\left( \frac{-(Z+2*k*L)^2}{2\ SGZ_i^{\,2}} \right) \right] \right.$$

$$\left. * \sum_{j=1}^{5} (WT_j * QE_j * PD_{ij}) \right\}$$

where n = total number of elements, CNT = number of multiple reflections required for convergence, U = wind speed, L = mixing height, $SGZ_i$ = vertical dispersion function for ith element, $QE_j$ = central sub-element line source strength for ith element, $WT_j$ = source strength weighting factor for jth sub-element, and $PD_{ij}$ = normal probability density function for jth sub-element of ith element. $PD_{ij}$ is calculated by use of a fifth order polynomial approximation.

CALINE3 treats the region directly over the roadway as a mixing zone in which there are uniform emissions and turbulence. Initial vertical dispersion is formulated as a function of mixing zone residence time and roadway half-width and is used to account for the thermally and mechanically enhanced dispersion over and downwind of the roadway arising from the passage of the vehicles.

In this dispersion treatment wind speed normalized concentration will be a function of emissions, wind direction, and stability.

One of the problems encountered with virtually all existing dispersion models is that they do not predict concentrations on the roadway. The CALINE3 model was chosen for this application because it can predict the concentration in a mixed cell over the roadway. The effects of this limitation should be examined using actual data gathered in a field program designed to study this problem.

2.5.1.2 Street Canyons

Dispersion on a roadway with tall buildings on both sides is greatly influenced by the presence of the buildings. The street-canyon dispersion treatment used in the commuter exposure model is based on the empirical street-canyon model developed by Johnson et al.[11] and modified by Ludwig et al.[12]. Their studies give evidence of a helical air circulation in street canyons, as illustrated in Figure 3. The concentration arising from street-canyon emissions on the leeward side of buildings is given by:

$$X_{\ell} = \frac{KQ_{\ell}}{\left(U+0.5\right)\left[\left(x^2+z^2\right)^{1/2}+L_o\right]}.$$

where

$X_\ell$ = concentration on leeward side of street ($g/m^3$)

$Q_\ell$ = line source emission rate (g/m/sec)

K = empirically derived nondimensional constant $\simeq 7$

U = wind speed (m/sec)

x and z = horizontal and vertical distance of the receptor relative to the center of the traffic lane (m)

$L_o$ = dimension representing vehicle size $\simeq$ 2 m.

The concentration on the windward side of the street is given by:

$$X_w = \frac{KQ_\ell\ (H-z)}{W(U+0.5)H}$$

where

$X_w$ = concentration on windward side of street ($g/m^3$)

H = average building height (m)

W = street width (m).

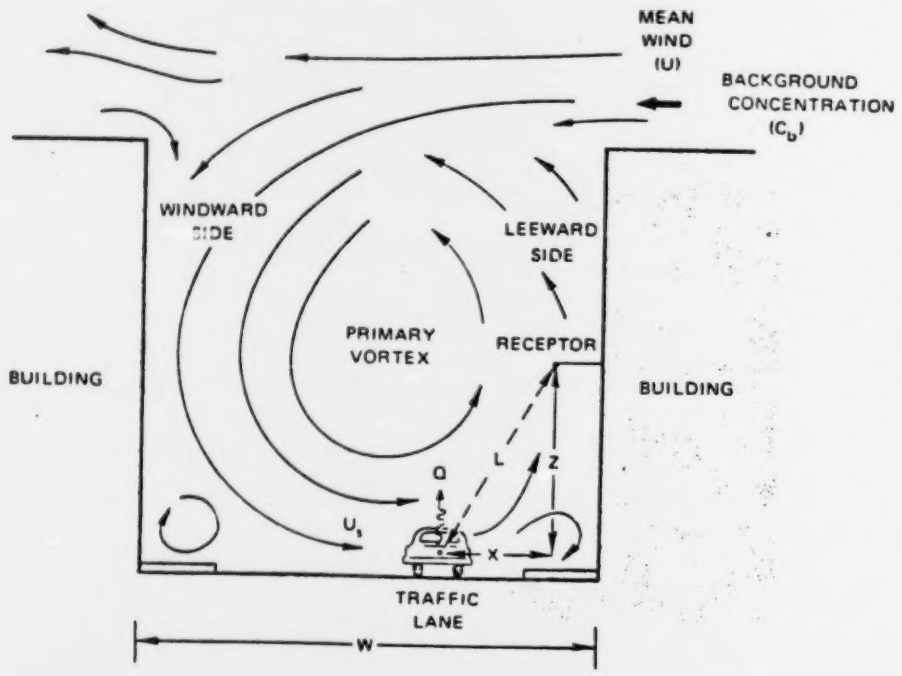


FIGURE 3 SCHEMATIC OF CROSS–STREET CIRCULATION BETWEEN BUILDINGS

In the commuter exposure model, the concentration on the roadway is assumed to be the average of the concentration on the windward and leeward sides of the street. Since the receptor is on the roadway, x and z are zero.

Substituting, and combining the above equations gives:

$$X = \frac{1}{2}\left[\frac{KQ_\ell}{(U+0.5)L_o} + \frac{KQ_\ell}{W(U+0.5)}\right]$$

$$= \frac{KQ_\ell}{2(U+0.5)}\left(\frac{1}{L_o} + \frac{1}{W}\right).$$

Since W is usually considerably larger than $L_o$, the $1/W$ term is small in comparison with the $1/L_o$ term. Considering this, the concentration relationship resembles that of a box model.

Thus, concentrations in street canyons are described by the time-dependent parameters of emissions and wind speed.

2.5.1.3. Computation of Concentration Statistics

The two dispersion methodologies discussed previously are used to compute exposures resulting from pathway sources when the commuter exposure model is run in either the short-term or the annual model.

When the commuter exposure model is run in the short-term mode, it makes computations of concentrations resulting from pathway sources in the following manner. Beginning with the first segment of the first pathway, it determines whether the segment is a street canyon or a non-street-canyon roadway. Using the input wind speed, wind direction, and stability, and the emission rate generated by the emissions module, the appropriate dispersion treatment is used to compute the concentration

on the segment. (If the segment is a street canyon, only the wind speed and emission rate are required.) Then, the concentration is multiplied by the travel time on the segment to yield an exposure on the segment. The model repeats the procedure for each segment of a pathway and sums the segment exposures to produce a pathway exposure. The model cycles through all pathways and calculates an exposure from pathway sources for each pathway.

When the model is run in the annual mode, it attempts to produce exposure statistics representative of the various meteorological conditions and emissions that occur during a typical year. If a model individually computed the morning and evening computer exposures for each day of the year, for several years, to ensure a representative "average" year's statistics, a very large number of computations would need to be made, at considerable cost. To avoid that, the model is designed to compute exposures only once for each combination of conditions.

The parameters that determine the concentration and vary with time are wind speed, wind direction, atmospheric stability, and emissions. Concentration can be normalized with respect to wind speed (in the street-canyon treatment, with respect to wind speed plus 0.5). Thus, separate computations need be made only for various combinations of wind direction, stability and emissions. Let wind direction be divided into 16 classes, stability into five classes, and emissions into morning and evening values. All combinations of those classes make up 160 cases.

Morning and evening emission rates and travel times are passed from the traffic and emissions portions of the model to the dispersion portion. It computes exposure in the following manner. As in the short-term mode,

it begins with the first segment of the first pathway and determines the segment's roadway type. If the roadway type is not a street canyon, the CALINE3 dispersion treatment is used to compute wind-speed-normalized concentrations on the segment for each of the 160 cases. If the segment is a street canyon, there is no dependence on wind direction or stability, so normalized concentrations are computed for two cases: morning and evening emissions. Once the set of normalized concentrations is computed, each concentration is multiplied by the appropriate travel time on the segment (morning or evening) to produce a set of exposures on the segment. The model repeats the procedure for each segment of a pathway and sums exposures from all non-street canyon segments of the pathway for each of the 160 cases. Two other sums are created for the pathway: the sums of exposures on street-canyon segments for morning and evening commutes. Those exposures must be stored separately because they are normalized by wind speed plus 0.5, instead of just wind speed, as on the non-street-canyon segments. The model cycles through all pathways and produces a set of exposures from pathway sources for each pathway. The 162 values for each pathway (160 exposures for non-street-canyon exposures), along with the 10 exposure values for each pathway resulting from non-pathway sources (described in the next section) are used to develop the annual commuter exposure statistics.

### 2.5.2 Dispersion of Non-Pathway Source Emissions

In general, the portion of the total pathway integrated concentration (exposure) that results from non-pathway sources is amall in comparison to the portion resulting from traffic on the commuter pathways themselves. Therefore, a very simple emissions and dispersion treatment is

used, both to reduce computational time on the computer and to simplify the data required to be input by the user.

The line-source emissions on non-pathways have been aggregated into area source emissions from grid squares, according to the methodology previously presented. The approach used to compute the concentrations along the commute pathways resulting from the area source emissions is the so-called Hanna-Gifford[13] dispersion treatment. The basic assumption of the treatment is that the area source strength in a metropolitan area varies by less than a factor of 10 over distances of a few kilometers. That assumption permits the horizontal cross-wind dispersion component to be neglected in comparison with the vertical component. If the area sources are a gridded system, with grid spacing of one to 10 km, the concentration in grid 0 can be calculated according to the formula:

$$X = \sqrt{\frac{2}{\pi}} \frac{(\Delta x/2)^{1-b}}{Ua(1-b)} \left\{ Q_o + \sum_{i=1}^{N} Q_i \left[ (2i+1)^{1-b} - (2i-1)^{1-b} \right] \right\}$$

where X = concentration in grid 0
Q = emission rate
U = wind speed
$\Delta x$ = grid spacing
N = number of upwind grid squares
a,b = constants, dependent on stability

and the subscript i refers to the upwind grid squares, with zero denoting the central square, 1 denoting the square next upwind, and so forth.

The equation can be simplified by taking advantage of the fact that

the influence on $X_c$ of source areas far upwind from the central area is small due to the rapid decrease of terms multiplying $Q_i$ as i increases. Making the assumption that $Q_i \approx Q_o$, the equation can be approximated in the following manner:

$$X = \frac{CQ_o}{U}$$

where

$$C = \sqrt{\frac{2}{\pi}} \frac{D^{1-b}}{a(1-b)}$$

and D = a constant related to city size. The values used for C for various stability regimes are shown in Table 2. They are based on values suggested by Hanna[14].

Table 2

VALUES OF THE CONSTANT C FOR VARIOUS STABILITIES

| Stability | C |
|---|---|
| Very unstable | 50. |
| Unstable | 50. |
| Neutral | 200. |
| Estimated Pasquill's "D" (average) | 225. |
| Stable | 600. |

Thus, for any point on a pathway, the approximated form of the equation can be used to compute the concentration from area sources. The commuter model computes those concentrations on a pathway-by-pathway basis. For a given pathway, the model takes the first segment and determines which grid squares contain the segment end points. The coordinates of the midpoint of the segment are generated, and the gird square in which the midpoint is located is determined. For each of these points, a concentration normalized by wind speed is calculated according to the relationship discussed above. Concentrations would be calculated, for example, for the point $P_1$, $P_2$ (the midpoint), and point $P_3$ in Figure 4. The traffic model will have generated the times at which the average vehicle reaches $P_1$, $P_2$, and $P_3$. From them, two travel times can be derived: (1) the travel time from $P_1$ to $P_2$, called $T_1$, and (2) the travel time from $P_2$ to $P_3$, called $T_2$. Thus,

$$T_1 = t_2 - t_1 \text{ and } T_2 = t_3 - t_2.$$

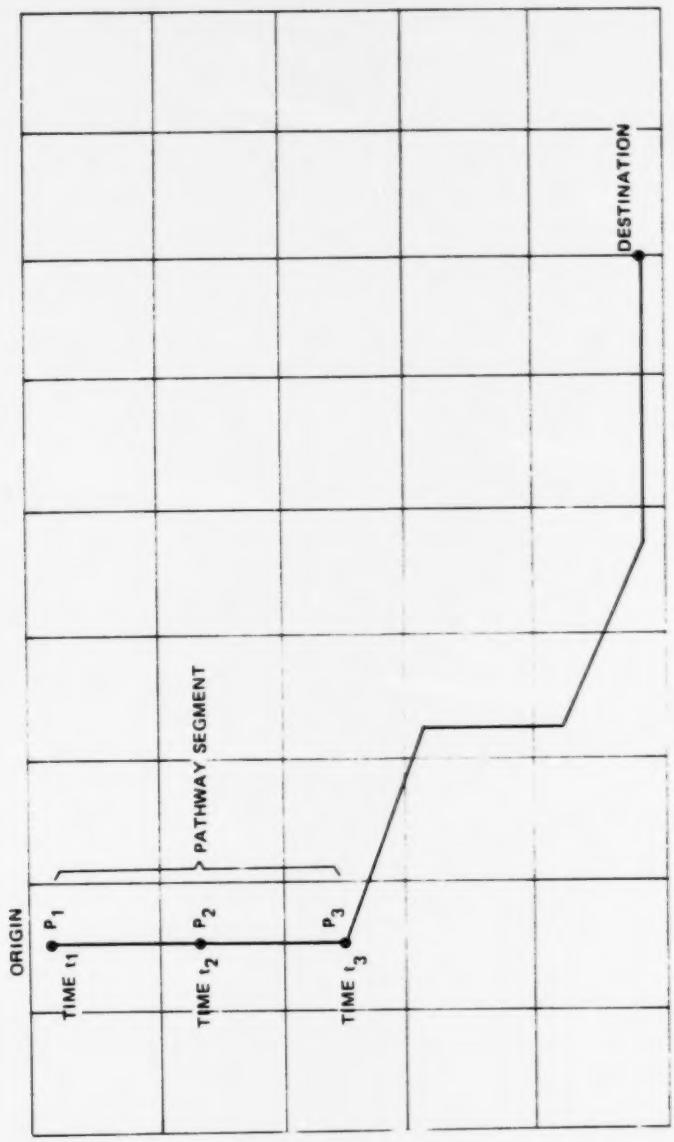


FIGURE 4 ILLUSTRATION OF INTEGRATION TECHNIQUE FOR NON-PATHWAY CONCENTRATIONS

The normalized integrated concentration over the segment (the exposure) is given by:

$$EU = \int_{t_1}^{t_3} XU \, dt.$$

Through a stepwise integration, the following relationship results:

$$EU = \int_{t_1}^{t_2} XU \, dt + \int_{t_1}^{t_3} XU \, dt$$

$$= \left( \frac{X_1U + X_2U}{2} \right) T_1 + \left( \frac{X_2U + X_3U}{2} \right) T_2$$

$$= \frac{1}{2} \left[ X_1UT_1 + X_2U(T_1 + T_2) + X_3UT_2 \right] .$$

This normalized exposure applies to only one segment of a pathway. The model computes similar exposures for all segments of a pathway, and sums the results to yield the normalized pathway exposures resulting from non-pathway sources.

When the model is in the annual mode, wind-normalized exposures on all pathways are computed for five stability classes and two times of day (morning and evening). Thus, 10 exposure values are stored for each pathway for use in developing the statistics that describe commuter exposure.

When the model is in the short-term mode, the exposure on each pathway for the input wind speed and stability is computed using the model-generated emission rate.

### 2.5.3 On-Roadway/In-Vehicle Concentration Relationship

A search of the literature has yielded a limited amount of information about the relationship between the concentration on the roadway and the concentration within a vehicle. Several papers[15, 16, 17] discuss in-vehicle concentrations, but only two references[18, 19] could be found that presented measurements of concentrations both inside and outside a vehicle. In one study[18] the pollutants measured were $O_3$, CO, NO, and $NO_x$; measurements were made on only one vehicle with the windows closed and the air conditioner set on maximum or normal for most of the time. The study concluded that concentrations of CO, NO, and $NO_x$ inside a vehicle are about equal to that on the outside, while the $O_3$ inside concentration was a factor of 3 or 4 lower than the outside concentration, due to decay of $O_3$ on the surfaces within the vehicle. The other study[19] discussed measurements of particulate lead; levels inside the vehicle were approximately three-quarters of the levels outside the vehicle.

Therefore, since so little work has been directed toward establishing a data base suitable for deriving on-roadway/in-vehicle relationships, the commuter exposure model assumes the concentrations at the two locations are identical. The commuter model will be of most use in predicting carbon monoxide exposure, and one of the studies discussed above found inside and outside CO concentrations to be about equal.

Even if the assumption is made that all of the pollutant outside the vehicle will find its way inside the vehicle, a question still remains concerning the time response of the inside concentration with respect to changes in the outside concentration. Evidently, the response is very rapid, since both concentrations have been found to be approximately the

same. Further reinforcement to this theory is given by Chaney,[17] who measured concentrations within a vehicle with the windows closed and the fan on maximum. He often found a distinct increase in CO concentration when his vehicle was passed by another vehicle. The increase occurred a few seconds after the passage of the vehicle.

When a good body of data becomes available, on-roadway/in-vehicle concentration relationships will be able to be established. They will most likely depend on the state of the windows (closed or open), the state of the fan, air conditioner and heater, the vehicle model, and whether there is smoking occurring in the vehicle. It appears that for CO, inside and outside concentrations will be similar. However, it is expected that in some vehicles, with the windows closed and no ventilation system in operation, inside concentrations, while responding to perturbations in outside concentrations, in effect will be filtered.

If on-roadway/in-vehicle concentration relationships were available, and assuming the correction factor would be directly proportioned to concentration, application of the relationships could be made through modifications of the modeling package in one of two places. If the relationships were a function of model year, they would need to be applied in the emission factor preprocessor, before the individual emission factors for each model year are weighted by the fraction of travel for each model year. If the relationships were not model year dependent, they could be applied after concentrations have been calculated, but before exposure statistics are tabulated.

## 2.6. Commuter Exposure Statistics

The exposures computed for each pathway for each mode of model operation were discussed in the previous sections. In addition to the exposures, the model stores the total travel time or times on each pathway and the average number of commuters using the pathway. The commuter exposure statistics developed by the model form the previously computed values and the manner in which the model computes those statistics for each mode of model operation are outlined in the following paragraphs.

### 2.6.1. Short-term Statistics

When the model is run in the short-term mode, commuter exposures are output in several forms. One type of output is a list of the exposure on each pathway arising from pathway, non-pathway, and all sources for the meteorological and traffic conditions that are input to the model. The list also includes the pathway travel time and the average concentration for the pathway. Next, the average and standard deviation of pathway exposure are printed. The remaining two outputs are data that can be used to construct a histogram. The range of exposures found on all pathways are divided into several classes. For each class two parameters are listed: (1) the percentage of the commuting population (commuting vehicles multiplied by the average number of commuters per vehicle) treated by the model that experience exposure levels in the class; and (2) the probability of experiencing the exposure levels in the class (i.e., the percentage of time commuters are exposed to the levels of the exposure class).

The first form of output is found by simply adding the exposures on each pathway resulting from pathway and from non-pathway sources and

listing these exposures, their sum, the travel time, and the average concentration (pathway exposure divided by travel time). The average and standard deviation of the values are computed using standard methods. These numbers describe the spatial variation of exposures. The histogram data is produced by: (1) computing a range of exposure values to be included in each exposure class; (2) determining in which class the total exposure value on each pathway lies and assigning the pathway's commuters and travel time mulitplied by commuters (commute-seconds) to that class; and (3) tabulating the number of commuters and the commuter-weighted travel times in each class. Dividing the number of commuters associated with each class by the total number of commuters on the pathway network yields the percentage of commuters exposed to each range of exposure values. Dividing the commute-seconds associated with each class by the total commute-seconds on the pathway network gives the probability of occurrence of the exposure levels in each class.

2.6.2. Annual Statistics

Two forms of annual statistics from which histograms can be made are produced by the model when it is in the annual mode. In addition, subsets of those statistics may be otuput at the user's discretion. The two kinds of annual histogram data that are generated are: (1) the percentage of commuters exposed to various classes (ranges) of exposure; and (2) the probability of experiencing various classes of exposure (i.e., the percentage of time commuters are exposed to various classes of exposure).

The following discussion describes the manner in which the model produces both of those types of statistics. The model begins with the first pathway. As stated previously, several normalized exposures will

have been computed for each pathway: 160 normalized exposures arising from non-street-canyon pathway sources (for 16 wind directions, five stabilities, and morning and evening emission rates); two normalized exposures resulting from street-canyon sources (for morning and evening emission rates); and ten normalized exposures resulting from non-pathway sources (for five stabilities, and morning and evening emission rates). The model takes the first of the 160 cases (one combination of wind direction, stability, and morning or evening emissions) and multiplies the exposrue by one of six wind speed values. Next, the normalized street-canyon exposure for the corresponding time (morning or evening) is multiplied by the same wind speed plus 0.5. Finally, the normalized non-pathway source exposure for the corresponding time and stability is multiplied by the wind speed, and all three exposure values are summed. The model determines the exposure class in which this total exposure value lies, and it multiplies the pathway travel time by the number of commuters on the pathway. It then weights both the number of commuters (commuting vehicles multiplied by the number of commuters per vehicle) on the pathway and the pathway commute-seconds by the frequency of occurrence of the case's wind speed, wind direction, and stability for the emission time period (morning or evening). The two weighted numbers are stored for the exposure class. The model then cycles to the next wind speed and repeats the procedure, then to the next case (of the 160) for each wind speed, and so forth. For each pathway, the weighted number of commuters are summed for each exposure class, as are the weighted commute-seconds. Finally, the percentage of commuters in each exposure class is found by dividing the number in the class by the total commuters;

percentages of commute-seconds (probabilities) will be found similarly.

If the user desires one or more subsets of the preceding information, he may request it with model input. For example, if pathway X is of particular interest, the user can input a flag and the pathway number to produce either or both types of histogram data for pathway X only.

One other type of output is available when the model is in the annual mode. If information about the variation with meteorology of exposure on a particular pathway is desired, the user inputs a flag, the pathway number, and the meteorological conditions of interest, and the model lists the morning and evening exposures on the pathway for each combination of meteorological parameters.

### 2.6.3 Graphical Display of Statistics

Histograms provide a convenient means of depicting the statistics generated by the model. The commuter exposure model has a subroutine, GRAF, containing the variables, definitions, and instructions needed to plot histograms. Classes of exposure would be plotted on the abscissa, while the percentage of commuters or probabilities would be plotted on the ordinate. The actual code to do the plotting was not included because of a lack of generality among line printers. For more detailed information concerning the mechanics of adding a plotting capability, see subroutine GRAF and Section 5.3.1.3 of The User's Guide.

SECTION 3

GLOSSARY OF SYMBOLS

Occasionally a model user will wish to modify a program to suit a particular application. Also, as the state-of-the-art in simulation modeling improves, it may be advantageous to modify the modeling methodology. For such reasons, a glossary of the symbols used in the commuter exposure modeling package is included in this section of the User's Guide.

The symbols are divided into two groups: The first group is used in the emissions preprocessing program, PREPRS, and the second group is used in the main model, CEMAP. For both groups only the major variables and indices are included in the glossary. The model input variables, appearing on card types 1P through 6P and 1M through 9M, are not included, since they are defined in Table 3 of The User's Guide and discussed in the text.

The glossary contains only those PREPRS symbols that were created specifically for the preprocessor. The user is referred to MOBILE1 documentation[4] for definition of the variables used in the MOBILE1 subroutines and to the modal model documentation for the relavent variables in subroutine MODMOD. In the CEMAP program, the variable names used in subroutine ROAD were taken from the CALINE3 code. For their definition the user is referred to the CALINE3 User's Guide.[10]

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GLOSSARY OF SYMBOLS FOR PROGRAM PREPRS

ACFAC (IAMPM, IMY, IP) air conditioning correction factor

CLDCOR (IMY, IS, IP) temperature/cold start/speed correction factor for modal emission factors for evening (annual mode) or commute of interest (short-term mode)

EMAD (I1, I2) light duty vehicle acceleration and deceleration emissions

EMAD (IAGE, I2) composite acceleration and deceleration emission contribution (corrected for air conditioning and proportion of travel)

EMAD1 (ITIME, IPOLL, ISPD) composite vehicle acceleration and deceleration

EMADMY (IAGE, I2) light duty vehicle acceleration and deceleration emissions

EMCR1 (ITIME, IPOLL, ISPD) composite vehicle cruise emissions

EMCRMY (IAGE, I2) light duty vehicle cruise emissions

EMCRUZ (I1, I2) light duty vehicle cruise emissions

EMCRUZ (IAGE, I2) composite cruise emission contribution (corrected for air conditioning and proportion of travel)

FMODY (I) fraction of travel accounted for by vehicles of age I

I1 modal model vehicle type index

I2 pollutant index; 2=CO (I2 always=2)

I4 vehicle age index (relative to 1975)

IAC passes various airconditioning percentages to MOBILE1

IAGE vehicle age index

IAMPM time index; 1=AM, 2=PM (annual mode); IAMPM=1 (short-term mode)

ICC passes various percentages of cold-starting catalyst vehicles to MOBILE1

ICH passes various percentages of hot-starting catalyst vehicles to MOBILE1

IFILE logical unit device to which output is written to be read by CEMAP (set=8 in a data statement)

II speed index for FTP emission factors

IICH stored data: 100 percent hot transient vehicles

IICS stored data: 0 percent cold starting or hot starting vehicles

ILOC location index

ILOOP index controlling the number of cycles made through MOBILE1 subroutine

IMY model year index

INCC passes various percentages of cold starting non-catalyst vehicles to MOBILE1

IP pollutant index; 2=CO (IP always=2)

IPOLL pollutant index; 2=CO (IPOLL always=2)

IREAD logical unit device from which reading is done (set=5 in a data statement)

IS speed index for modal emission factors

ISPD traffic speed index for modal speed; ISPD=1 to 6 representing 5 to 30 mph in 5 mph increments

ISTOP flag to stop computation after all data is read because input data is in error

ITEMP passes various temperatures to MOBILE1

ITIME time index; 1=AM, 2=PM (annual mode); ITIME=1 (short-term mode)

IWRI logical unit device to which writing is done (set=6 in a data statement)

MAXAGE maximum age of vehicles being modeled, 1951 vehicles being the oldest

MAXCY calendar year for which modal emissions are calculated

MODAGE oldest vehicles included in the modal model

RATEM (IAMPM, IS, IP) ratio of composite to LDV emission factors

RATIO (IMV, IS, IP) ratio of CLDCOR to WRMCOR

RSPD passes various speeds to MOBILE1

TOTEM (IAMPM, II, IP) array in which NON-CBD pathway emission factors and emission factors for gridded VMT are temporarily stored

UPDATE (I4, ILOC) array to estimate modal emissions of post-1975 vehicles

WRMCOR (IMY, IS, IP) temperature/speed correction factor for 100% warm operation for modal emission factors

GLOSSARY OF SYMBOLS FOR PROGRAM CEMAP

ARRIVE arrival rate of vehicles at a toll booth, vehicles per minute

AVCONC (IP, IPATH, IAMPM) average pathway concentration

C the capacity of an intersection approach under signalization, vehicles per hour

C(IAMPM, ISTWD, IWSTEM) normalized concentration on non-street canyon roadways

CMNO2A (ICLASS, IP, KP2) sum of AM commute-seconds in exposure class; then percentage of commute-seconds in class for pathways chosen with option 2

CMNO2P (ICLASS, IP, KP2) sum of PM commute-seconds in exposure class; then percentage of commute-seconds in class for pathways chosen with option 2

CMNSUM (ICLASS, IP, IAMPM) network sum of commute-seconds in each exposure class; then probability of experiencing exposure levels in class

CNPLST (IPATH, IP) concentration resulting from non-pathway sources on last segment of pathway, short-term mode

COMO1A (ICLASS, IP, KP1) sum of AM commuters in each exposure class; then percentage of commuters in class for pathways chosen with option 1

COMO1P (ICLASS, IP, KP1) sum of PM commuters in each exposure class; then percentage of commuters in class for pathways chosen with option 1

COMSUM (ICLASS, IP, IAMPM) network sum of commuters in each exposure class; then percentage of commuters in class

CONST (ISTAB) C in Hanna-Gifford dispersion equations

DBAR average waiting time at a toll booth

DEL (IPATH, LINK, M9) average delay at a signalized intersection, seconds

DELBAK time spent traversing a freeway backup, minutes

DISBAK distance traversed in a freeway backup, miles

EGRID (IGRID, IP, IAMPM) grid square emission rate

EINTVL (IP) range of exposure covered by each class

EMAD1 (IAMPM, IP, IMSPD) modal acceleration/deceleration emission factor for CBD pathway VMT

EMCR1 (IAMPM, IP, IMSPD) modal cruise emission factor for CBD pathway VMT

EMIDLE (IP) idle emission factor for CBD pathway VMT

ERATEA (IPATH, LINK, IP) segment emission rate, AM or short-term mode

ERATEP (IPATH, LINK, IP) segment emission rate, PM

EXDIST the length of a link

EXNPAM (IPATH, ISTAB, IP) exposure (normalized if annual mode) from non-pathway sources, AM or short-term mode

EXNPPM (IPATH, ISTAB, IP) exposure (normalized if annual mode) from non-pathway sources, PM

EXNSAM (IPATH, ISTWD, IP) pathway exposure (normalized if annual mode) on non-street canyon roadways, AM or short-term mode

EXNSPM (IPATH, ISTWD, IP) pathway exposure (normalized if annual mode) on non-street canyon roadways, PM

EXP (IPATH, IP, IAMPM) pathway exposure

EXP3 (IOPT3, IP, IAMPM) exposure for pathway and meteorological conditions chosen with option 3

EXPNP (IPATH, IP, IAMPM) total non-pathway exposure (annual mode)

EXPP (IPATH, IP, IAMPM) total pathway exposure (annual mode)

EXPSUM (IP, IAMPM) sum of pathway exposures; then average pathway exposure

EXSQSM (IP) sum of the squares of pathway exposures, short-term mode

EXST (IPATH, IP, IAMPM) pathway exposure (normalized if annual mode) in street canyons; then in short-term mode only sum of street canyon and non-street canyon exposure on the pathway

GRDFAC (IAMPM, LOC, IP) emission factor for gridded VMT

GREXP (IP) largest exposure value computed

HALF one-half of the length of a link

IAMPM time index; 1=AM, 2=PM (annual mode); IAMPM=1 (short-term mode)

ICLASS exposure class index

IFILE logical unit device from which file written by preprocessor is read (set=8 in a data statement)

IGRID grid square index

IMSPD traffic speed index for modal speed; IMSPD=1 to 6 representing 5 to 30 mph in 5 mph increments

IOPT3 index for meteorological conditions chosen with option 3

IP pollutant index; 2=CO (IP always = 2)

IPATH index of pathway numbers

IREAD logical unit device from which reading is done (set = to 5 in a data statement)

ISPD traffic speed index; ISPD=1 to 11 representing 10 to 60 mph in 5 mph increments

ISTAB stability class index; 1 = very unstable, 2 = moderately unstable, 3 = slightly unstable, 4 = neutral, 5 = stable (annual mode), ISTAB = 1 (short-term mode)

ISTWD combined stability/wind direction class index; 5 stability classes x 16 wind direction classes (annual mode), ISTWD=1 (short-term mode)

IWRI logical unit device to which writing is done (set = to 6 in a data statement)

IWSTEM reduced wind speed class index used in ROAD; reduced to vary from classes 1 to 3 for computational efficiency (annual mode), IWSTEM=1 (short-term mode)

JGRID1 (IPATH, LINK) grid square in which first endpoint of segment lies

JGRID2 (IPATH, LINK) grid square in which second endpoint of segment lies

JGRIDM (IPATH, LINK) grid square in which midpoint of segment lies

JOPT1 number of pathways for which optional output 1 was chosen

JOPT2 number of pathways for which optional output 2 was chosen

JOPT3 number of meteorological conditions for which optional output 3 was chosen

JWD wind direction class index

JWS wind speed class index

K9 flag specifying whether traffic direction coincides with commute direction; 1=yes, 0=no

KP1 index for pathways chosen with option 1

KP2 index for pathways chosen with option 2

LINK index of segment number

LOC locale index

LSPEED integer value of the speed on a link to the nearest 5 mph

M9 traffic direction index; 1=inbound, 2=outbound

MON index specifying the month

NBAR average number of vehicles queued at a toll booth

NINT number of intersections

NPH number of separate green phases of a traffic signal cycle

NSTAB3 (IOPT3) stability class for meteorological conditions chosen with option 3

NWD3 (IOPT3) wind direction class for meteorological conditions chosen with option 3

NWS3 (IOPT3) wind speed class for meteorological conditions chosen with option 3

OUTFAC (IAMPM, ISPD, IP) emission factor for non-CBD pathway VMT

P(IPATH, LINK, M9) proportion of vehicles that stop at an intersection travelling in the direction designated by M9

Q (IPATH, LINK, M9) average queue length at a signalized intersection, vehicles

QDIS average queue length, miles

QLNGTH queue length at a toll booth, miles

QUEBAK interim estimate of the number of vehicles per lane in a freeway backup

R ratio of volume to capacity on an intersection approach

RHO arrival rate divided by service rate at a toll booth

SERVIC service or departure rate of vehicles from a toll booth, vehicles per minute

SKIP the sum of R's for controlling approaches to an intersection

SPEED speed on a link calculated by capacity restraint relationships

STDEV standard deviation of pathway exposure, short-term mode

THEAD time headway between vehicles, minutes

TOTBAK number of vehicles per lane in a freeway backup

TOTTT (IPATH, IAMPM) total pathway travel time (seconds)

TT1 (IPATH, LINK, IAMPM) travel time from 1st endpoint to midpoint of segment (minutes)

TT2 (IPATH, LINK, IAMPM) travel time from midpoint to 2nd endpoint of segment (minutes)

VC volume divided by capacity (consistent units)

W (IPATH, LINK) segment width

WDIR (JWD) central wind direction of wind direction class

WSPD (JWS) central wind speed of wind speed class

XGPLUS x-coordinate of east side of grid square

XMID x-coordinate of midpoint of segment

YGPLUS y-coordinate of north side of grid square

YMID y-coordinate of midpoint of segment

SECTION 4

FLOWCHARTS

This section contains flowcharts of most of the subroutines in the commuter exposure modeling package. They are included for the use of the person wishing to modify the model for a particular application or for use in updating the model to reflect improvements in traffic, emissions, and dispersion modeling.

Figure 5 is a flowchart of the main program of the emissions preprocessor, PREPRS. This figure also appears in The User's Guide, but is repeated here to contribute to the clarity of the other subroutines. Figures 6, 7, and 8 are flowcharts of subroutines FTP, CORFAC, AND MODMOD, which compute FTP emission factors, modal correction factors, and modal emission factors. Subroutines INPT and OUTPUT also were written specifically for the preprocessor to read input data and print and create files of output data. Flowcharts of these subroutines are not included because they simply perform straight-forward I/O operations. The remaining subroutines in PREPRS were taken from EPA's MOBILE1 program, as described in The User's Guide; they are not flowcharted here.

The main model, CEMAP, comprises fifteen subroutines and a BLOCK DATA subprogram . Figure 9 is a flowchart of the main program of CEMAP. As with PREPRS, above, this figure is also repeated from The User's Guide for completeness. The subroutine that reads the model input data, INDATA, has not been flowcharted because its function is simple and straight-forward.



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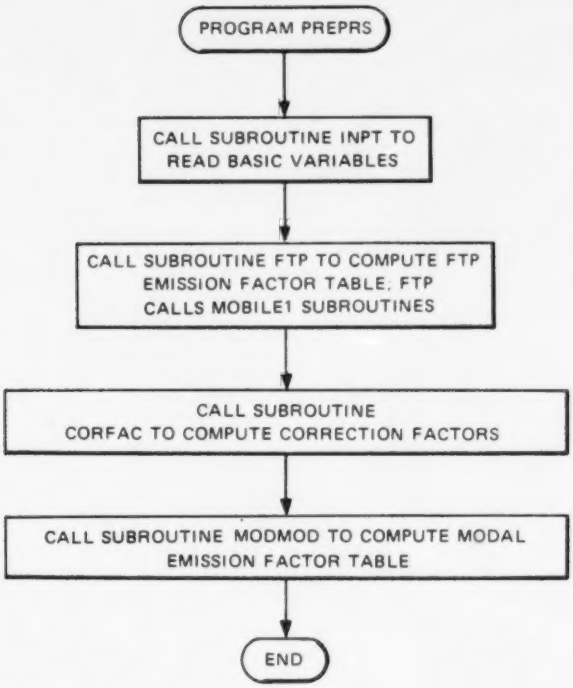
PROGRAM PREPRS
CALL SUBROUTINE INPT TO READ BASIC VARIABLES
CALL SUBROUTINE FTP TO COMPUTE FTP EMISSION FACTOR TABLE. FTP CALLS MOBILE1 SUBROUTINES
CALL SUBROUTINE CORFAC TO COMPUTE CORRECTION FACTORS
CALL SUBROUTINE MODMOD TO COMPUTE MODAL EMISSION FACTOR TABLE
END

FIGURE 5 FLOW CHART OF EMISSIONS PREPROCESSOR – MAIN PROGRAM

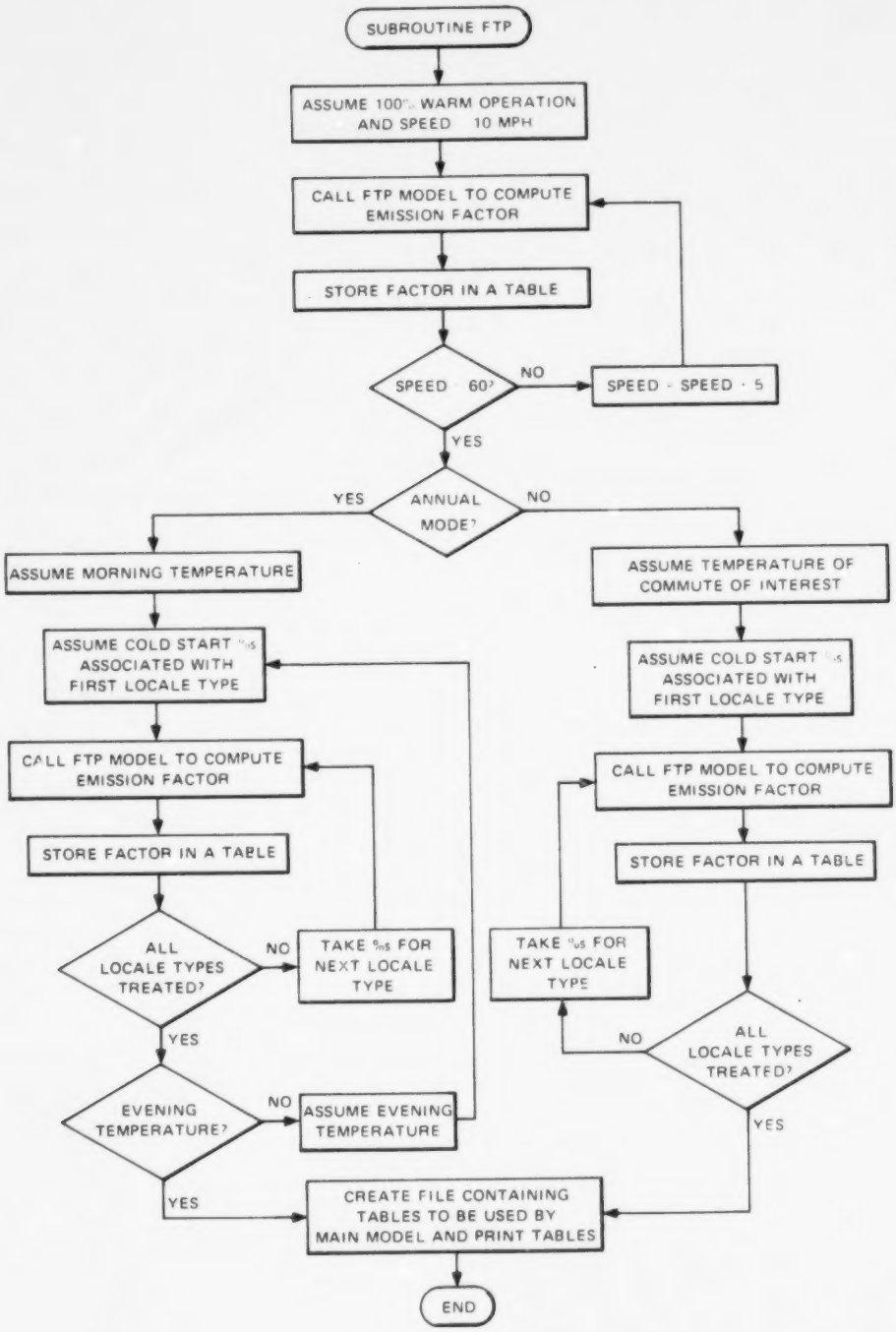


FIGURE 6 FLOWCHART OF EMISSIONS PREPROCESSOR – SUBROUTINE FTP

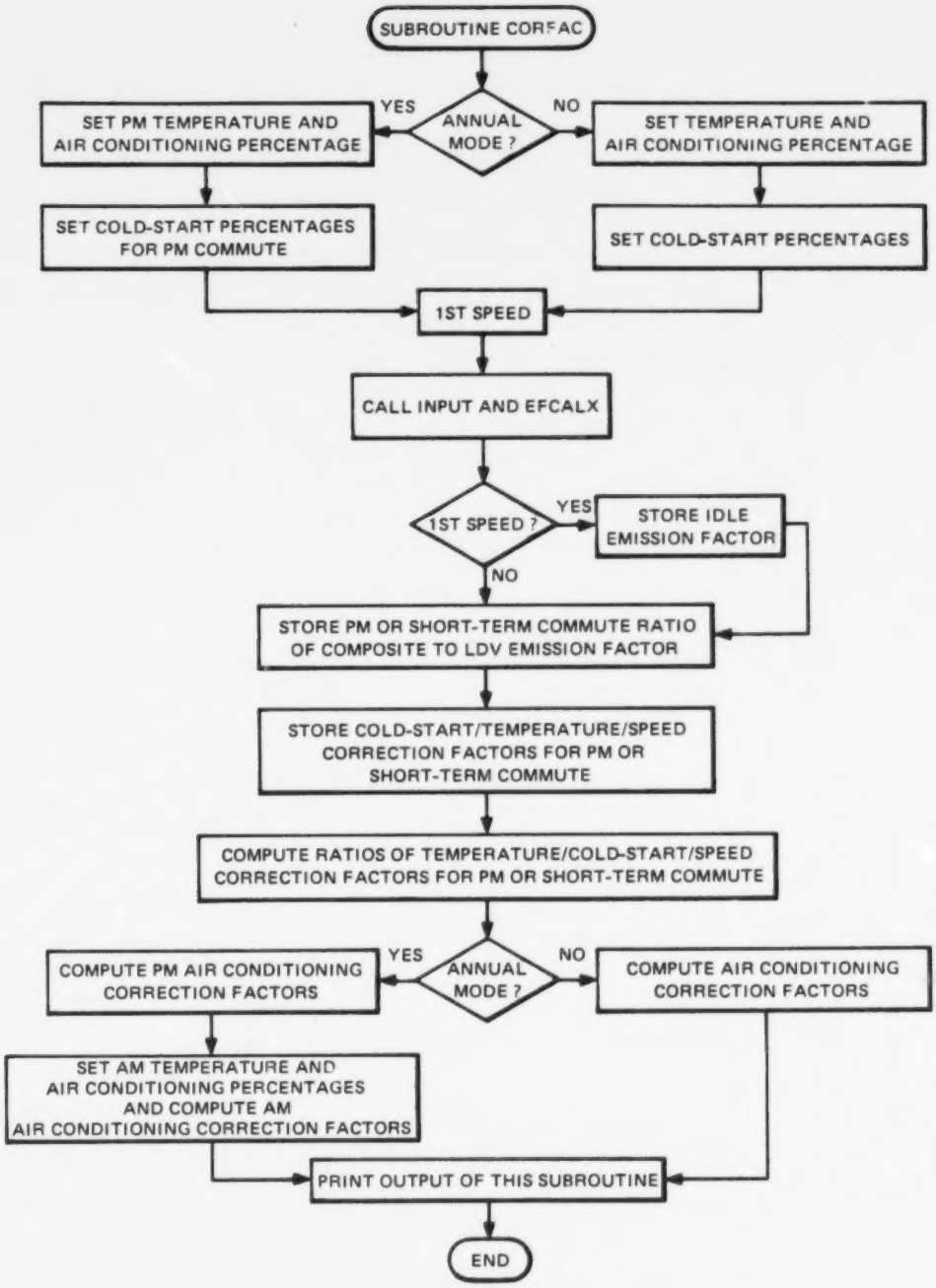
SUBROUTINE CORFAC
ANNUAL MODE ?
YES
NO
SET PM TEMPERATURE AND AIR CONDITIONING PERCENTAGE
SET TEMPERATURE AND AIR CONDITIONING PERCENTAGE
SET COLD-START PERCENTAGES FOR PM COMMUTE
SET COLD-START PERCENTAGES
1ST SPEED
CALL INPUT AND EFCALX
1ST SPEED ?
YES
NO
STORE IDLE EMISSION FACTOR
STORE PM OR SHORT-TERM COMMUTE RATIO OF COMPOSITE TO LDV EMISSION FACTOR
STORE COLD-START/TEMPERATURE/SPEED CORRECTION FACTORS FOR PM OR SHORT-TERM COMMUTE
COMPUTE RATIOS OF TEMPERATURE/COLD-START/SPEED CORRECTION FACTORS FOR PM OR SHORT-TERM COMMUTE
ANNUAL MODE ?
YES
NO
COMPUTE PM AIR CONDITIONING CORRECTION FACTORS
COMPUTE AIR CONDITIONING CORRECTION FACTORS
SET AM TEMPERATURE AND AIR CONDITIONING PERCENTAGES AND COMPUTE AM AIR CONDITIONING CORRECTION FACTORS
PRINT OUTPUT OF THIS SUBROUTINE
END

FIGURE 7 FLOWCHART OF SUBROUTINE CORFAC

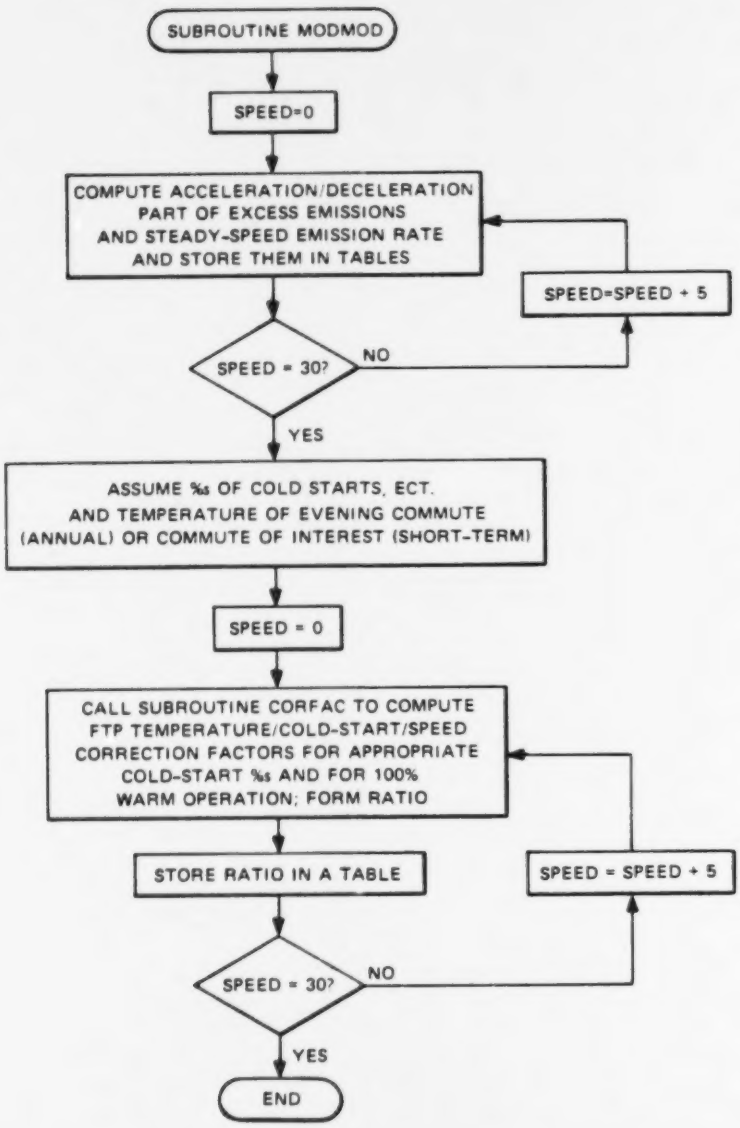
SUBROUTINE MODMOD
SPEED=0
COMPUTE ACCELERATION/DECELERATION PART OF EXCESS EMISSIONS AND STEADY-SPEED EMISSION RATE AND STORE THEM IN TABLES
SPEED=SPEED + 5
SPEED = 30?
NO
YES
ASSUME %s OF COLD STARTS, ECT. AND TEMPERATURE OF EVENING COMMUTE (ANNUAL) OR COMMUTE OF INTEREST (SHORT-TERM)
SPEED = 0
CALL SUBROUTINE CORFAC TO COMPUTE FTP TEMPERATURE/COLD-START/SPEED CORRECTION FACTORS FOR APPROPRIATE COLD-START %s AND FOR 100% WARM OPERATION; FORM RATIO
STORE RATIO IN A TABLE
SPEED = SPEED + 5
SPEED = 30?
NO
YES
END

FIGURE 8 FLOWCHART OF EMISSIONS PREPROCESSOR – SUBROUTINE MODMOD

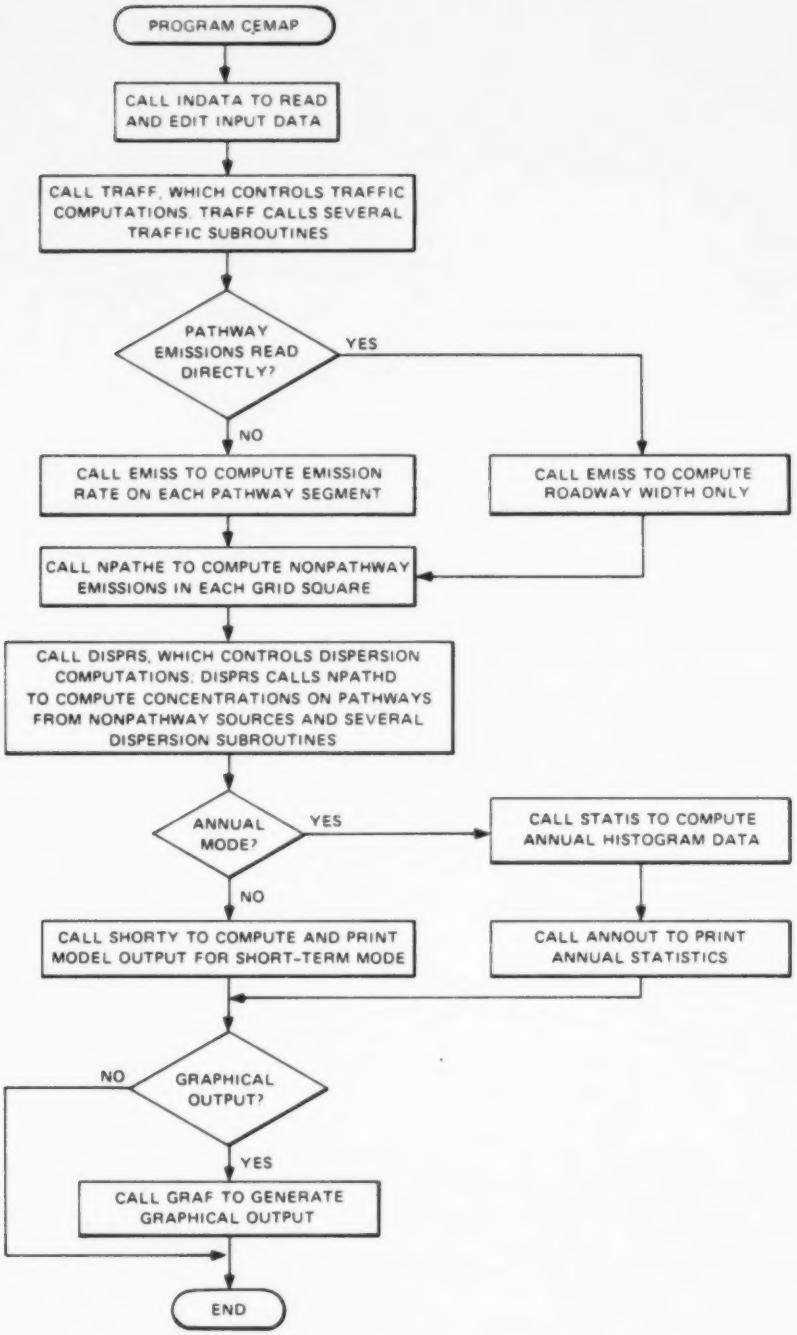
PROGRAM CEMAP
CALL INDATA TO READ AND EDIT INPUT DATA
CALL TRAFF, WHICH CONTROLS TRAFFIC COMPUTATIONS. TRAFF CALLS SEVERAL TRAFFIC SUBROUTINES
PATHWAY EMISSIONS READ DIRECTLY?
YES
NO
CALL EMISS TO COMPUTE EMISSION RATE ON EACH PATHWAY SEGMENT
CALL EMISS TO COMPUTE ROADWAY WIDTH ONLY
CALL NPATHE TO COMPUTE NONPATHWAY EMISSIONS IN EACH GRID SQUARE
CALL DISPRS, WHICH CONTROLS DISPERSION COMPUTATIONS. DISPRS CALLS NPATHD TO COMPUTE CONCENTRATIONS ON PATHWAYS FROM NONPATHWAY SOURCES AND SEVERAL DISPERSION SUBROUTINES
ANNUAL MODE?
YES
NO
CALL STATIS TO COMPUTE ANNUAL HISTOGRAM DATA
CALL SHORTY TO COMPUTE AND PRINT MODEL OUTPUT FOR SHORT-TERM MODE
CALL ANNOUT TO PRINT ANNUAL STATISTICS
GRAPHICAL OUTPUT?
NO
YES
CALL GRAF TO GENERATE GRAPHICAL OUTPUT
END

FIGURE 9 FLOW CHART OF MAIN CONTROL MODULE OF MAIN PORTION OF COMMUTER EXPOSURE MODEL

Figures 10 through 13 are flowcharts of the subroutines that simulate traffic flow for the model, while Figures 14 and 15 are flowcharts of the emission rate modeling procedure. Flowcharts of the dispersion subroutines are given in Figures 16 through 19. Finally, Figures 20, 21, and 22 show flowcharts of the subroutines that compute and print the model output statistics.

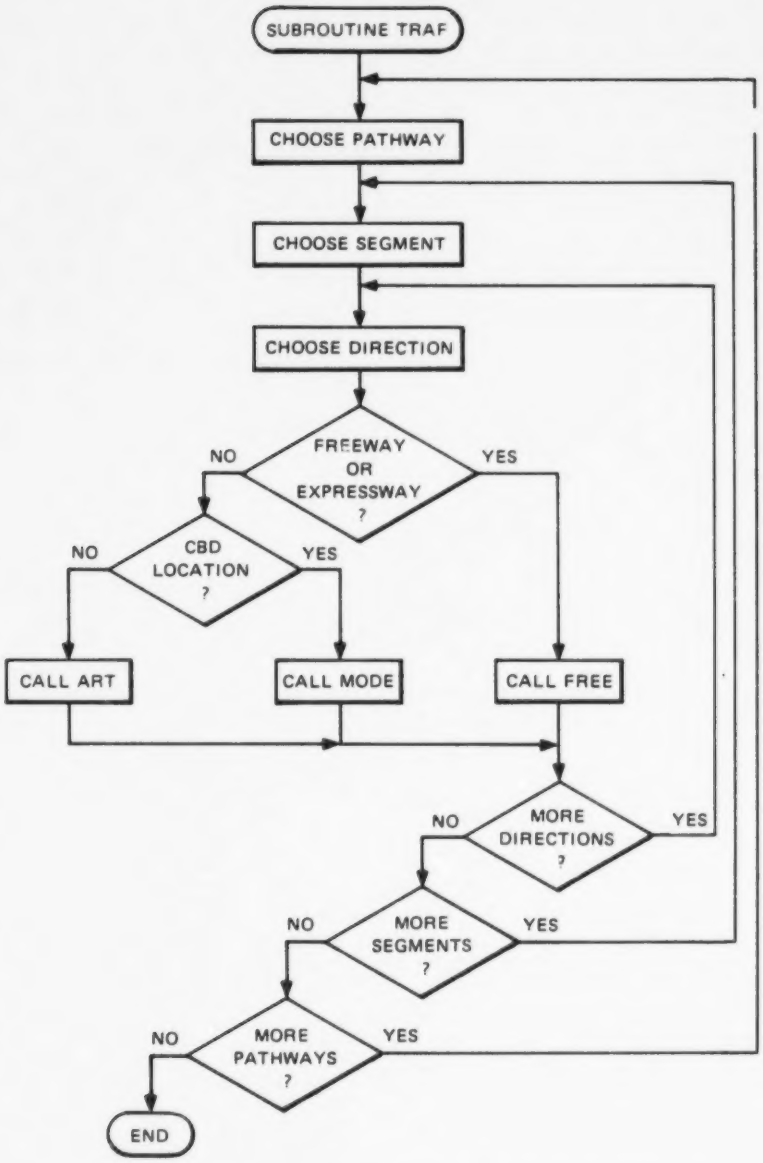


FIGURE 10 FLOWCHART OF SUBROUTINE TRAF

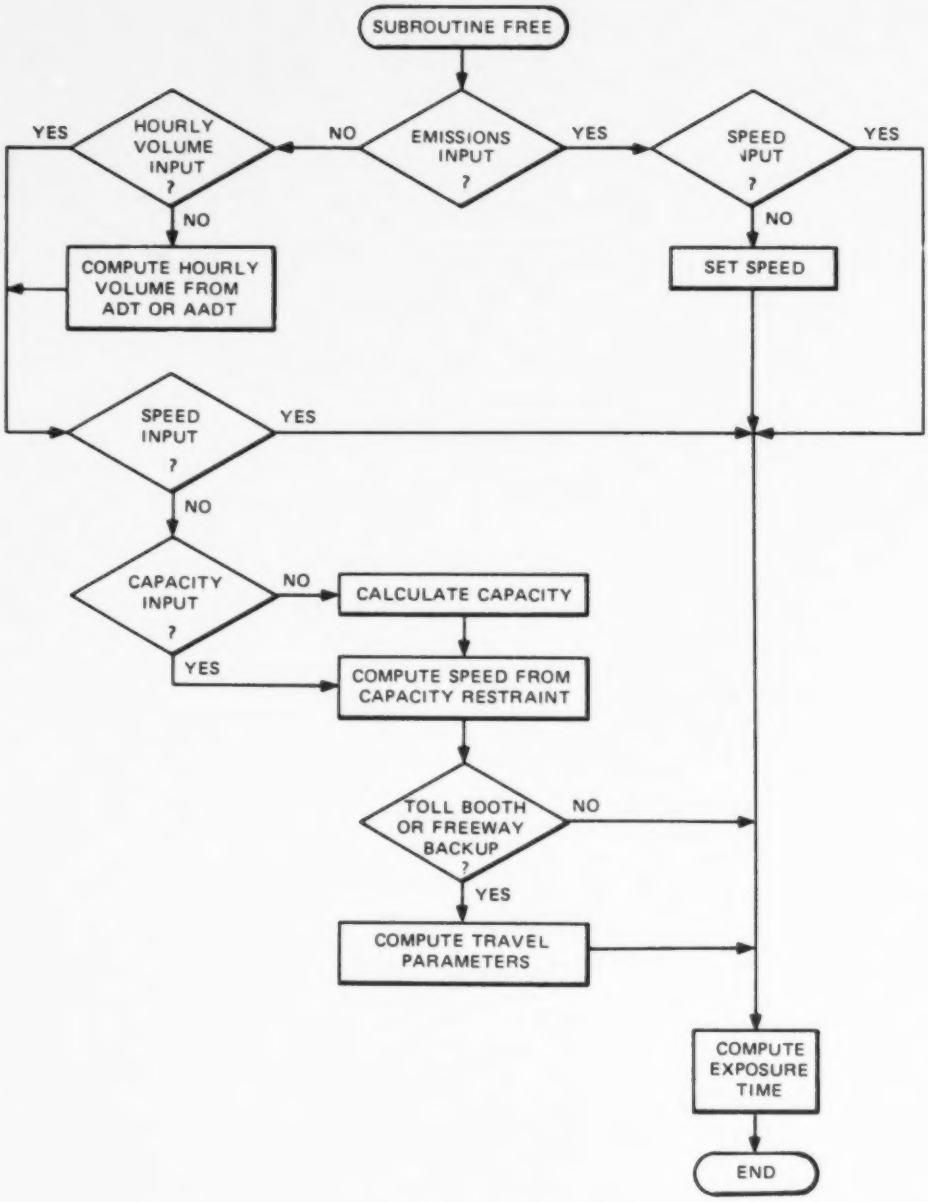


FIGURE 11 FLOWCHART OF SUBROUTINE FREE

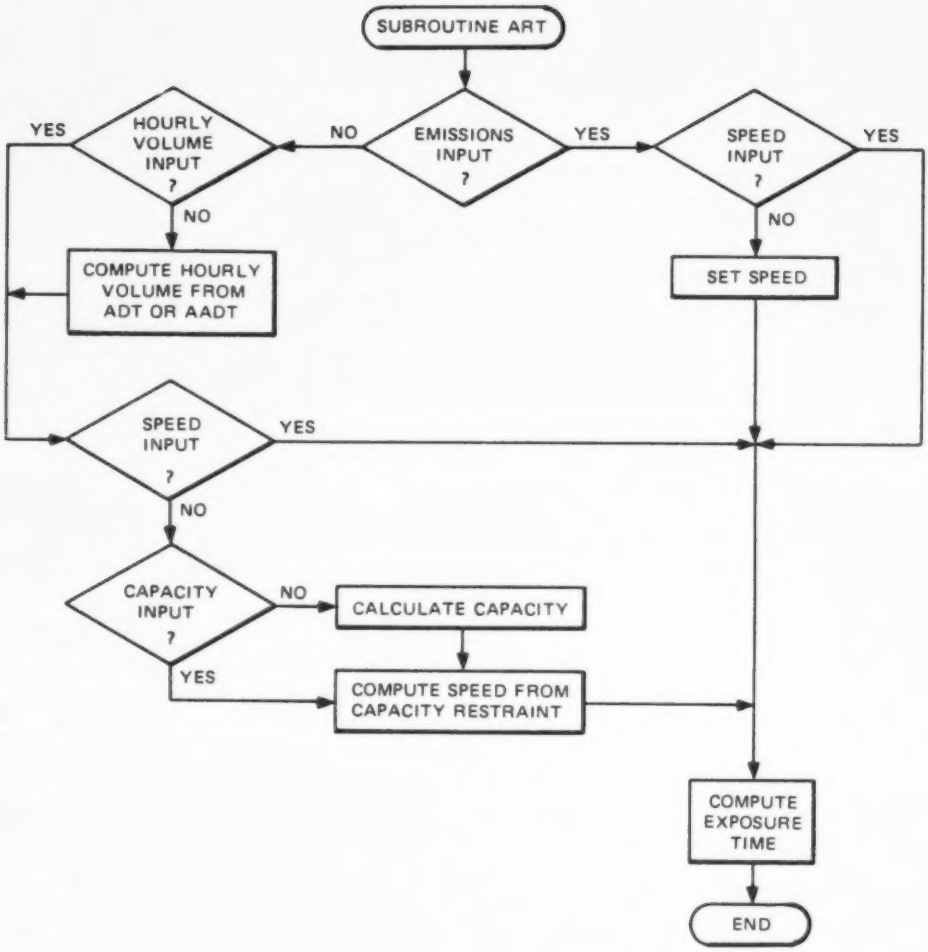


FIGURE 12 FLOWCHART OF SUBROUTINE ART

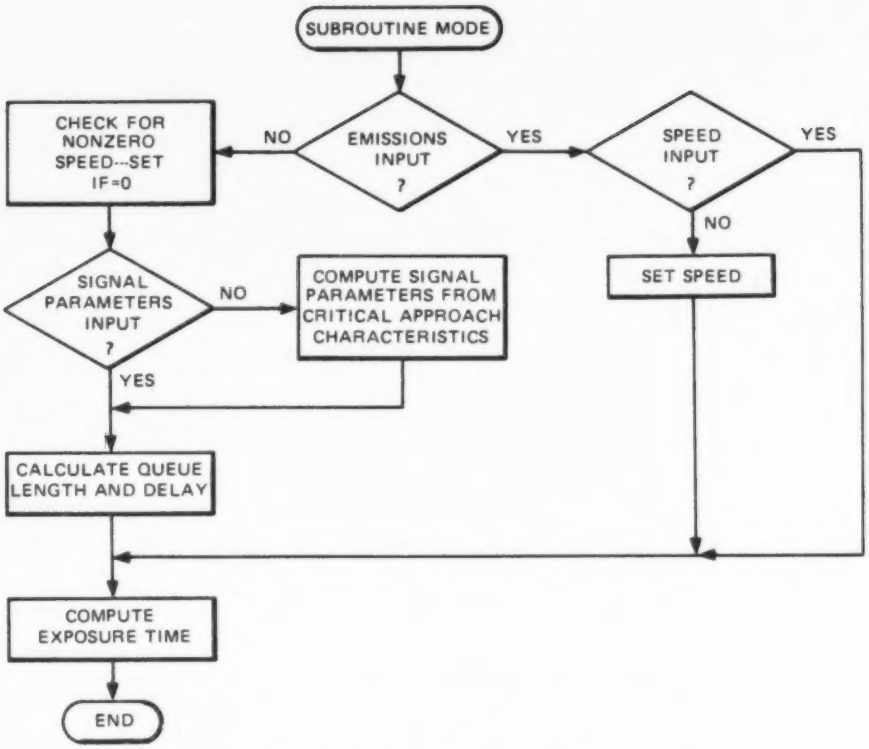


FIGURE 13 FLOWCHART OF SUBROUTINE MODE

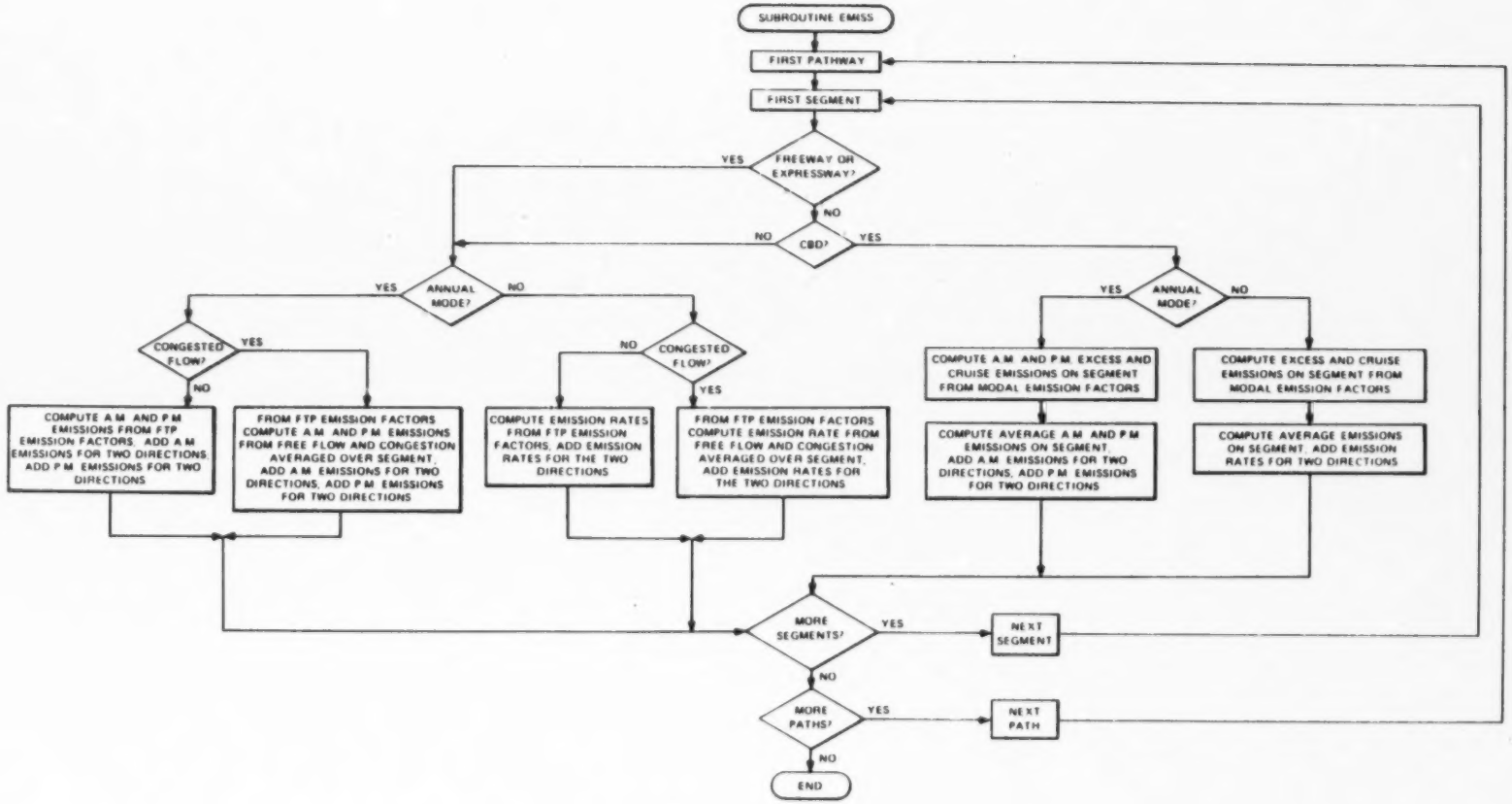
SUBROUTINE EMISS
FIRST PATHWAY
FIRST SEGMENT
FREEWAY OR EXPRESSWAY?
YES
NO
CBD?
NO
YES
ANNUAL MODE?
YES
NO
CONGESTED FLOW?
YES
NO
COMPUTE A M AND P M EMISSIONS FROM FTP EMISSION FACTORS, ADD A M EMISSIONS FOR TWO DIRECTIONS, ADD P M EMISSIONS FOR TWO DIRECTIONS
FROM FTP EMISSION FACTORS COMPUTE A M AND P M EMISSIONS FROM FREE FLOW AND CONGESTION AVERAGED OVER SEGMENT, ADD A M EMISSIONS FOR TWO DIRECTIONS, ADD P M EMISSIONS FOR TWO DIRECTIONS
NO
CONGESTED FLOW?
YES
COMPUTE EMISSION RATES FROM FTP EMISSION FACTORS, ADD EMISSION RATES FOR THE TWO DIRECTIONS
FROM FTP EMISSION FACTORS COMPUTE EMISSION RATE FROM FREE FLOW AND CONGESTION AVERAGED OVER SEGMENT, ADD EMISSION RATES FOR THE TWO DIRECTIONS
YES
ANNUAL MODE?
NO
COMPUTE A M AND P M EXCESS AND CRUISE EMISSIONS ON SEGMENT FROM MODAL EMISSION FACTORS
COMPUTE AVERAGE A M AND P M EMISSIONS ON SEGMENT, ADD A M EMISSIONS FOR TWO DIRECTIONS, ADD P M EMISSIONS FOR TWO DIRECTIONS
COMPUTE EXCESS AND CRUISE EMISSIONS ON SEGMENT FROM MODAL EMISSION FACTORS
COMPUTE AVERAGE EMISSIONS ON SEGMENT, ADD EMISSION RATES FOR TWO DIRECTIONS
MORE SEGMENTS?
YES
NEXT SEGMENT
NO
MORE PATHS?
YES
NEXT PATH
NO
END

FIGURE 14 FLOWCHART OF SUBROUTINE EMISS

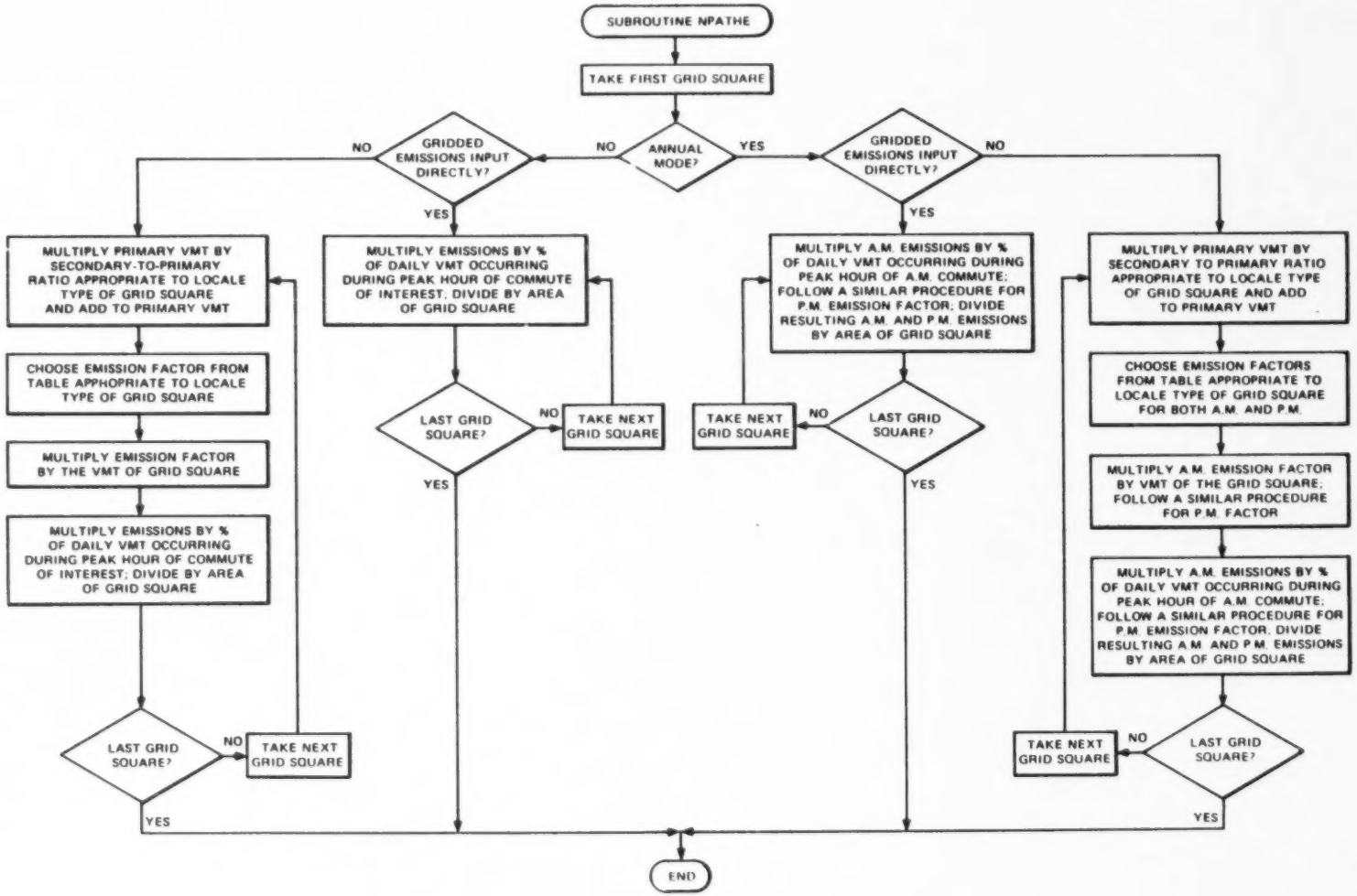
SUBROUTINE NPATHE
TAKE FIRST GRID SQUARE
ANNUAL MODE?
NO
YES
GRIDDED EMISSIONS INPUT DIRECTLY?
NO
YES
MULTIPLY PRIMARY VMT BY SECONDARY-TO-PRIMARY RATIO APPROPRIATE TO LOCALE TYPE OF GRID SQUARE AND ADD TO PRIMARY VMT
CHOOSE EMISSION FACTOR FROM TABLE APPHOPRIATE TO LOCALE TYPE OF GRID SQUARE
MULTIPLY EMISSION FACTOR BY THE VMT OF GRID SQUARE
MULTIPLY EMISSIONS BY % OF DAILY VMT OCCURRING DURING PEAK HOUR OF COMMUTE OF INTEREST; DIVIDE BY AREA OF GRID SQUARE
LAST GRID SQUARE?
NO
TAKE NEXT GRID SQUARE
YES
MULTIPLY EMISSIONS BY % OF DAILY VMT OCCURRING DURING PEAK HOUR OF COMMUTE OF INTEREST; DIVIDE BY AREA OF GRID SQUARE
LAST GRID SQUARE?
NO
TAKE NEXT GRID SQUARE
YES
GRIDDED EMISSIONS INPUT DIRECTLY?
NO
YES
MULTIPLY A.M. EMISSIONS BY % OF DAILY VMT OCCURRING DURING PEAK HOUR OF A.M. COMMUTE; FOLLOW A SIMILAR PROCEDURE FOR P.M. EMISSION FACTOR; DIVIDE RESULTING A.M. AND P.M. EMISSIONS BY AREA OF GRID SQUARE
TAKE NEXT GRID SQUARE
NO
LAST GRID SQUARE?
YES
MULTIPLY PRIMARY VMT BY SECONDARY TO PRIMARY RATIO APPROPRIATE TO LOCALE TYPE OF GRID SQUARE AND ADD TO PRIMARY VMT
CHOOSE EMISSION FACTORS FROM TABLE APPROPRIATE TO LOCALE TYPE OF GRID SQUARE FOR BOTH A.M. AND P.M.
MULTIPLY A.M. EMISSION FACTOR BY VMT OF THE GRID SQUARE; FOLLOW A SIMILAR PROCEDURE FOR P.M. FACTOR
MULTIPLY A.M. EMISSIONS BY % OF DAILY VMT OCCURRING DURING PEAK HOUR OF A.M. COMMUTE; FOLLOW A SIMILAR PROCEDURE FOR P.M. EMISSION FACTOR; DIVIDE RESULTING A.M. AND P.M. EMISSIONS BY AREA OF GRID SQUARE
TAKE NEXT GRID SQUARE
NO
LAST GRID SQUARE?
YES
END

FIGURE 15 FLOWCHART OF SUBROUTINE NPATHE

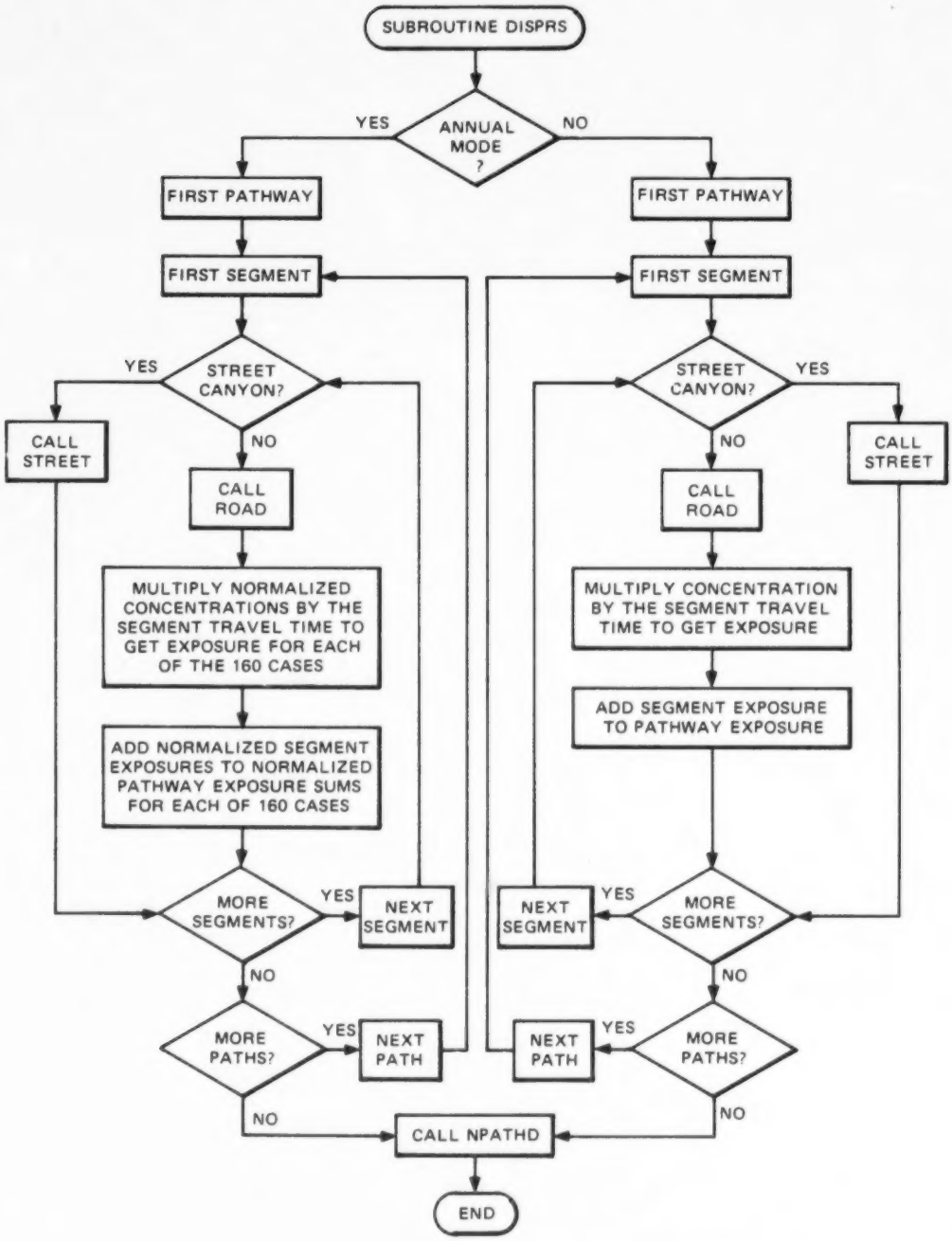


FIGURE 16 FLOWCHART OF SUBROUTINE DISPRS

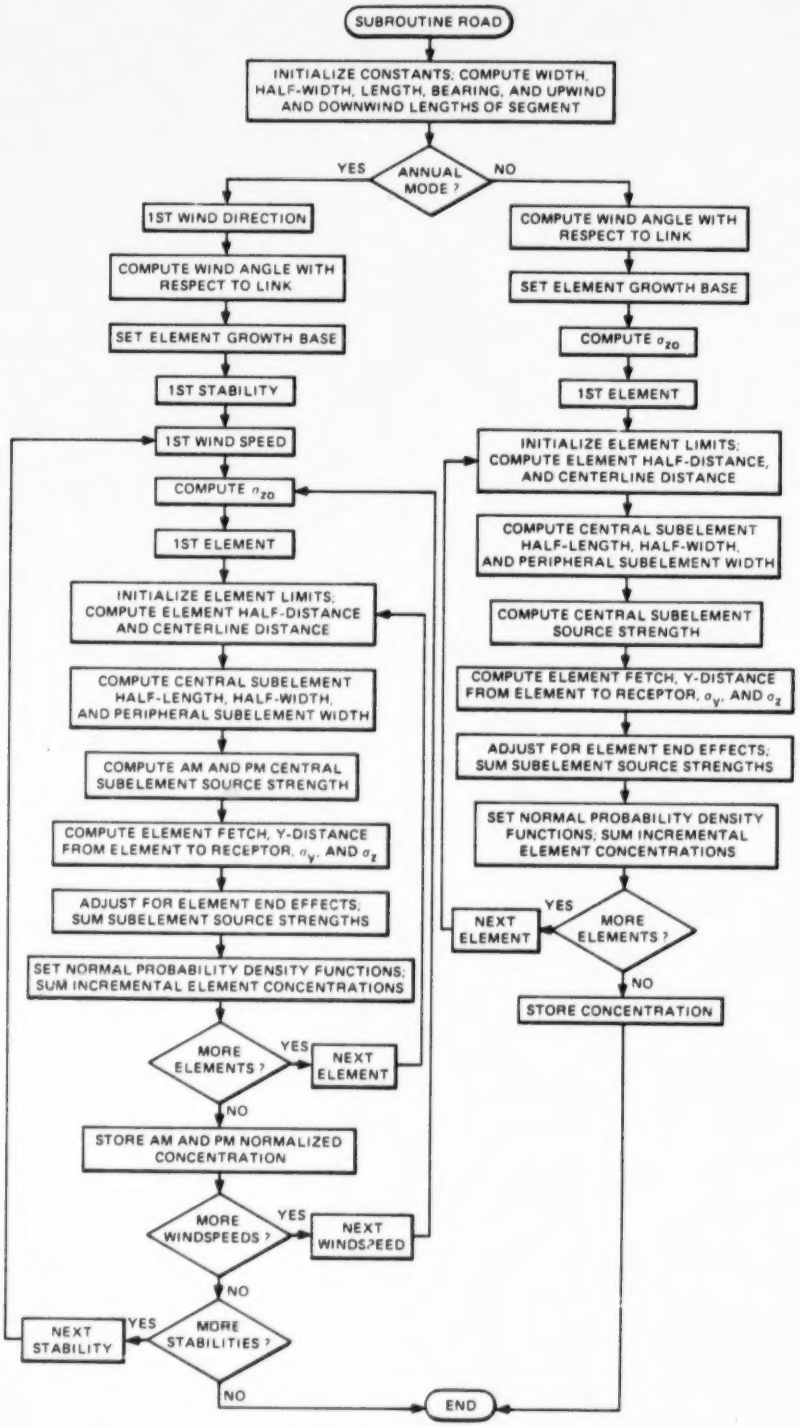
SUBROUTINE ROAD
INITIALIZE CONSTANTS; COMPUTE WIDTH, HALF-WIDTH, LENGTH, BEARING, AND UPWIND AND DOWNWIND LENGTHS OF SEGMENT
ANNUAL MODE ?
YES
NO
1ST WIND DIRECTION
COMPUTE WIND ANGLE WITH RESPECT TO LINK
SET ELEMENT GROWTH BASE
1ST STABILITY
1ST WIND SPEED
COMPUTE $\sigma_{z0}$
1ST ELEMENT
INITIALIZE ELEMENT LIMITS; COMPUTE ELEMENT HALF-DISTANCE AND CENTERLINE DISTANCE
COMPUTE CENTRAL SUBELEMENT HALF-LENGTH, HALF-WIDTH, AND PERIPHERAL SUBELEMENT WIDTH
COMPUTE AM AND PM CENTRAL SUBELEMENT SOURCE STRENGTH
COMPUTE ELEMENT FETCH, Y-DISTANCE FROM ELEMENT TO RECEPTOR, $\sigma_y$, AND $\sigma_z$
ADJUST FOR ELEMENT END EFFECTS; SUM SUBELEMENT SOURCE STRENGTHS
SET NORMAL PROBABILITY DENSITY FUNCTIONS; SUM INCREMENTAL ELEMENT CONCENTRATIONS
MORE ELEMENTS ?
YES
NEXT ELEMENT
NO
STORE AM AND PM NORMALIZED CONCENTRATION
MORE WINDSPEEDS ?
YES
NEXT WINDSPEED
NO
MORE STABILITIES ?
YES
NEXT STABILITY
NO
COMPUTE WIND ANGLE WITH RESPECT TO LINK
SET ELEMENT GROWTH BASE
COMPUTE $\sigma_{z0}$
1ST ELEMENT
INITIALIZE ELEMENT LIMITS; COMPUTE ELEMENT HALF-DISTANCE, AND CENTERLINE DISTANCE
COMPUTE CENTRAL SUBELEMENT HALF-LENGTH, HALF-WIDTH, AND PERIPHERAL SUBELEMENT WIDTH
COMPUTE CENTRAL SUBELEMENT SOURCE STRENGTH
COMPUTE ELEMENT FETCH, Y-DISTANCE FROM ELEMENT TO RECEPTOR, $\sigma_y$, AND $\sigma_z$
ADJUST FOR ELEMENT END EFFECTS; SUM SUBELEMENT SOURCE STRENGTHS
SET NORMAL PROBABILITY DENSITY FUNCTIONS; SUM INCREMENTAL ELEMENT CONCENTRATIONS
MORE ELEMENTS ?
YES
NEXT ELEMENT
NO
STORE CONCENTRATION
END

FIGURE 17 FLOWCHART OF SUBROUTINE ROAD

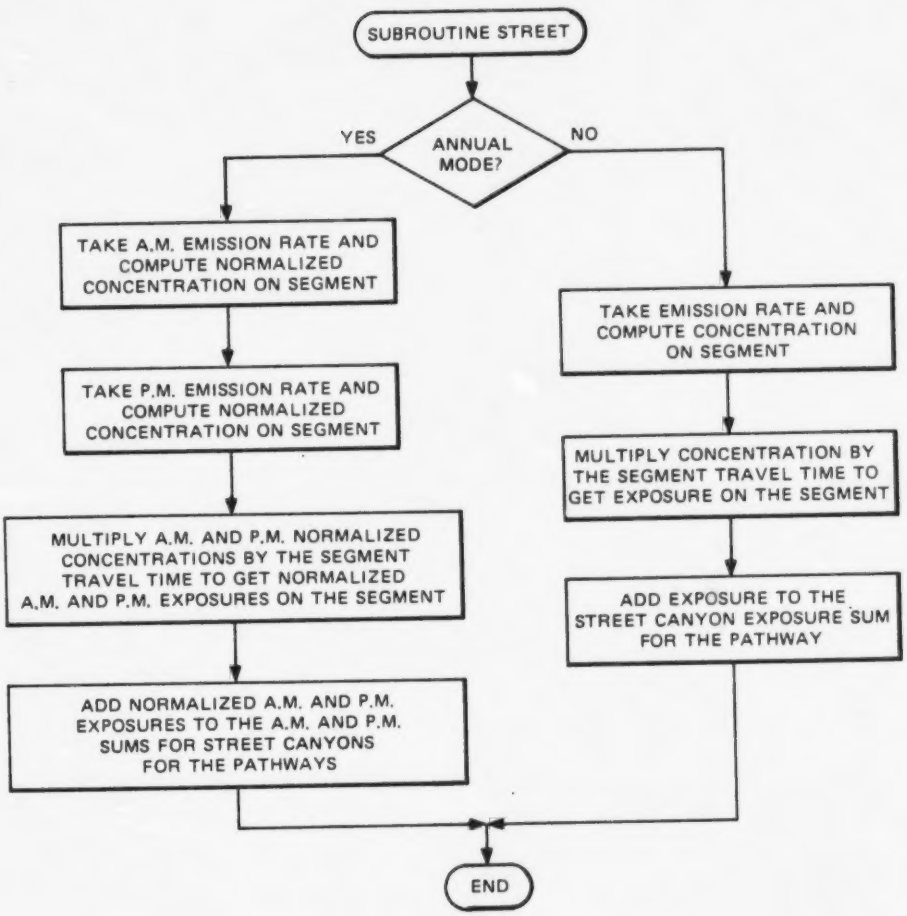
SUBROUTINE STREET
ANNUAL MODE?
YES
NO
TAKE A.M. EMISSION RATE AND COMPUTE NORMALIZED CONCENTRATION ON SEGMENT
TAKE P.M. EMISSION RATE AND COMPUTE NORMALIZED CONCENTRATION ON SEGMENT
MULTIPLY A.M. AND P.M. NORMALIZED CONCENTRATIONS BY THE SEGMENT TRAVEL TIME TO GET NORMALIZED A.M. AND P.M. EXPOSURES ON THE SEGMENT
ADD NORMALIZED A.M. AND P.M. EXPOSURES TO THE A.M. AND P.M. SUMS FOR STREET CANYONS FOR THE PATHWAYS
TAKE EMISSION RATE AND COMPUTE CONCENTRATION ON SEGMENT
MULTIPLY CONCENTRATION BY THE SEGMENT TRAVEL TIME TO GET EXPOSURE ON THE SEGMENT
ADD EXPOSURE TO THE STREET CANYON EXPOSURE SUM FOR THE PATHWAY
END

FIGURE 18 FLOWCHART OF SUBROUTINE STREET

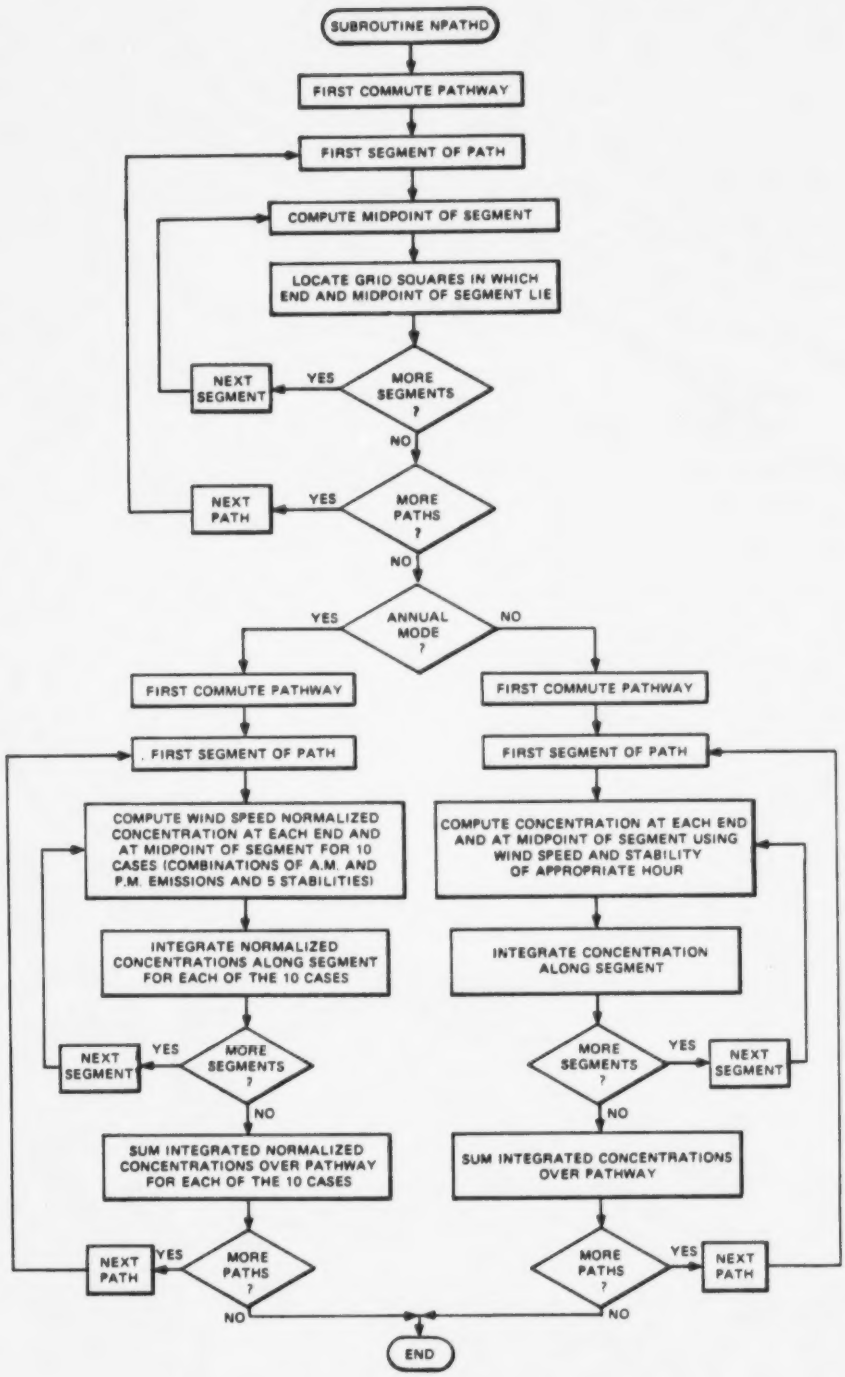


FIGURE 19 FLOWCHART OF SUBROUTINE NPATHD

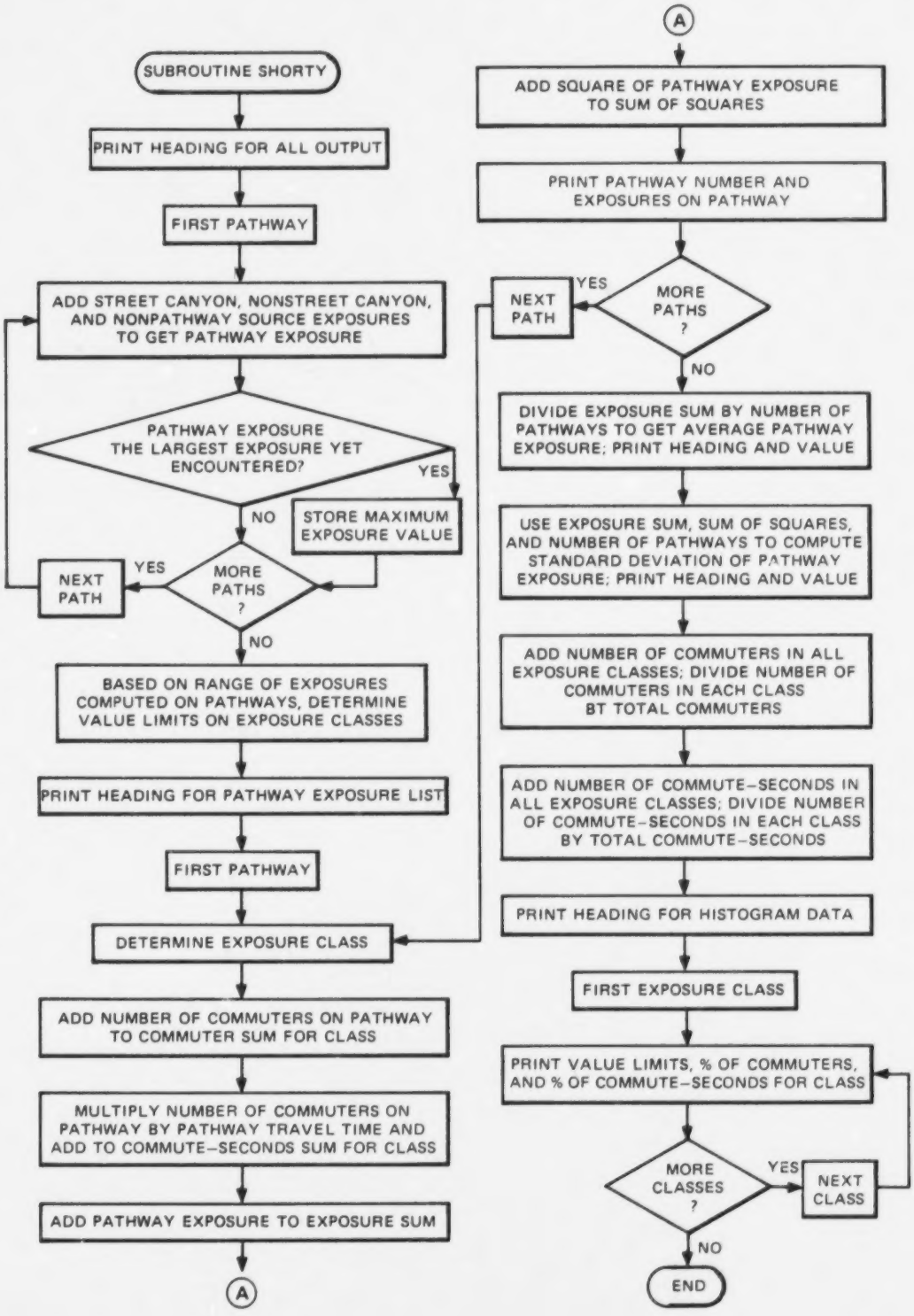
SUBROUTINE SHORTY
PRINT HEADING FOR ALL OUTPUT
FIRST PATHWAY
ADD STREET CANYON, NONSTREET CANYON, AND NONPATHWAY SOURCE EXPOSURES TO GET PATHWAY EXPOSURE
PATHWAY EXPOSURE THE LARGEST EXPOSURE YET ENCOUNTERED?
YES
NO
STORE MAXIMUM EXPOSURE VALUE
MORE PATHS ?
YES
NEXT PATH
NO
BASED ON RANGE OF EXPOSURES COMPUTED ON PATHWAYS, DETERMINE VALUE LIMITS ON EXPOSURE CLASSES
PRINT HEADING FOR PATHWAY EXPOSURE LIST
FIRST PATHWAY
DETERMINE EXPOSURE CLASS
ADD NUMBER OF COMMUTERS ON PATHWAY TO COMMUTER SUM FOR CLASS
MULTIPLY NUMBER OF COMMUTERS ON PATHWAY BY PATHWAY TRAVEL TIME AND ADD TO COMMUTE–SECONDS SUM FOR CLASS
ADD PATHWAY EXPOSURE TO EXPOSURE SUM
A
A
ADD SQUARE OF PATHWAY EXPOSURE TO SUM OF SQUARES
PRINT PATHWAY NUMBER AND EXPOSURES ON PATHWAY
MORE PATHS ?
YES
NEXT PATH
NO
DIVIDE EXPOSURE SUM BY NUMBER OF PATHWAYS TO GET AVERAGE PATHWAY EXPOSURE; PRINT HEADING AND VALUE
USE EXPOSURE SUM, SUM OF SQUARES, AND NUMBER OF PATHWAYS TO COMPUTE STANDARD DEVIATION OF PATHWAY EXPOSURE; PRINT HEADING AND VALUE
ADD NUMBER OF COMMUTERS IN ALL EXPOSURE CLASSES; DIVIDE NUMBER OF COMMUTERS IN EACH CLASS BT TOTAL COMMUTERS
ADD NUMBER OF COMMUTE–SECONDS IN ALL EXPOSURE CLASSES; DIVIDE NUMBER OF COMMUTE–SECONDS IN EACH CLASS BY TOTAL COMMUTE–SECONDS
PRINT HEADING FOR HISTOGRAM DATA
FIRST EXPOSURE CLASS
PRINT VALUE LIMITS, % OF COMMUTERS, AND % OF COMMUTE–SECONDS FOR CLASS
MORE CLASSES ?
YES
NEXT CLASS
NO
END

FIGURE 20 FLOWCHART OF SUBROUTINE SHORTY

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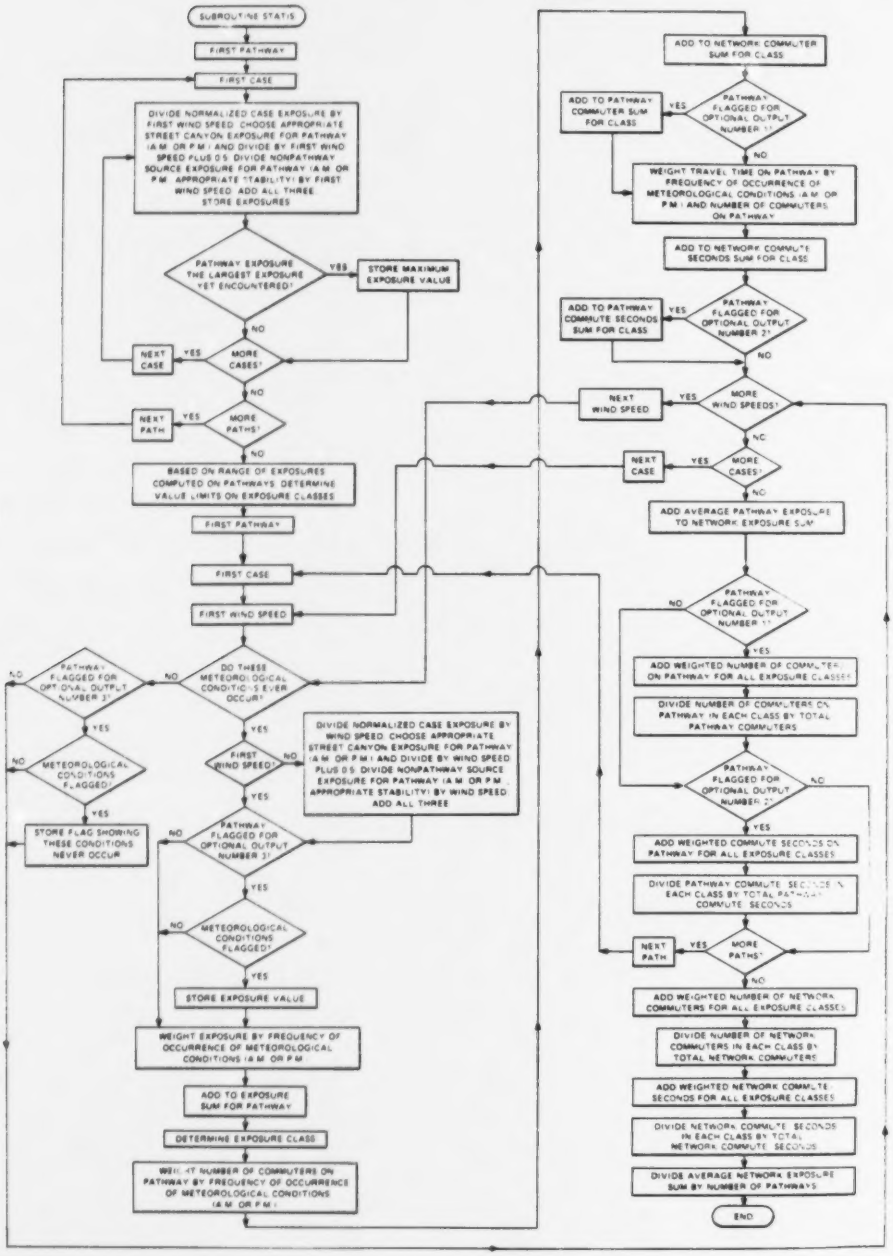
SUBROUTINE STATIS
FIRST PATHWAY
FIRST CASE
DIVIDE NORMALIZED CASE EXPOSURE BY FIRST WIND SPEED. CHOOSE APPROPRIATE STREET CANYON EXPOSURE FOR PATHWAY (A.M. OR P.M.) AND DIVIDE BY FIRST WIND SPEED PLUS 0.5. DIVIDE NONPATHWAY SOURCE EXPOSURE FOR PATHWAY (A.M. OR P.M. APPROPRIATE "STABILITY") BY FIRST WIND SPEED. ADD ALL THREE. STORE EXPOSURES
PATHWAY EXPOSURE THE LARGEST EXPOSURE YET ENCOUNTERED?
YES
STORE MAXIMUM EXPOSURE VALUE
NO
NEXT CASE
YES
MORE CASES?
NO
NEXT PATH
YES
MORE PATHS?
NO
BASED ON RANGE OF EXPOSURES COMPUTED ON PATHWAYS, DETERMINE VALUE LIMITS ON EXPOSURE CLASSES
FIRST PATHWAY
FIRST CASE
FIRST WIND SPEED
PATHWAY FLAGGED FOR OPTIONAL OUTPUT NUMBER 3?
NO
DO THESE METEOROLOGICAL CONDITIONS EVER OCCUR?
YES
METEOROLOGICAL CONDITIONS FLAGGED?
NO
STORE FLAG SHOWING THESE CONDITIONS NEVER OCCUR
YES
FIRST WIND SPEED?
NO
DIVIDE NORMALIZED CASE EXPOSURE BY WIND SPEED. CHOOSE APPROPRIATE STREET CANYON EXPOSURE FOR PATHWAY (A.M. OR P.M.) AND DIVIDE BY WIND SPEED PLUS 0.5. DIVIDE NONPATHWAY SOURCE EXPOSURE FOR PATHWAY (A.M. OR P.M. APPROPRIATE STABILITY) BY WIND SPEED. ADD ALL THREE
YES
PATHWAY FLAGGED FOR OPTIONAL OUTPUT NUMBER 3?
NO
METEOROLOGICAL CONDITIONS FLAGGED?
YES
STORE EXPOSURE VALUE
WEIGHT EXPOSURE BY FREQUENCY OF OCCURRENCE OF METEOROLOGICAL CONDITIONS (A.M. OR P.M.)
ADD TO EXPOSURE SUM FOR PATHWAY
DETERMINE EXPOSURE CLASS
WEIGHT NUMBER OF COMMUTERS ON PATHWAY BY FREQUENCY OF OCCURRENCE OF METEOROLOGICAL CONDITIONS (A.M. OR P.M.)
ADD TO NETWORK COMMUTER SUM FOR CLASS
ADD TO PATHWAY COMMUTER SUM FOR CLASS
YES
PATHWAY FLAGGED FOR OPTIONAL OUTPUT NUMBER 1?
NO
WEIGHT TRAVEL TIME ON PATHWAY BY FREQUENCY OF OCCURRENCE OF METEOROLOGICAL CONDITIONS (A.M. OR P.M.) AND NUMBER OF COMMUTERS ON PATHWAY
ADD TO NETWORK COMMUTE SECONDS SUM FOR CLASS
ADD TO PATHWAY COMMUTE SECONDS SUM FOR CLASS
YES
PATHWAY FLAGGED FOR OPTIONAL OUTPUT NUMBER 2?
NO
NEXT WIND SPEED
YES
MORE WIND SPEEDS?
NO
NEXT CASE
YES
MORE CASES?
NO
ADD AVERAGE PATHWAY EXPOSURE TO NETWORK EXPOSURE SUM
NO
PATHWAY FLAGGED FOR OPTIONAL OUTPUT NUMBER 1?
YES
ADD WEIGHTED NUMBER OF COMMUTERS ON PATHWAY FOR ALL EXPOSURE CLASSES
DIVIDE NUMBER OF COMMUTERS ON PATHWAY IN EACH CLASS BY TOTAL PATHWAY COMMUTERS
PATHWAY FLAGGED FOR OPTIONAL OUTPUT NUMBER 2?
NO
YES
ADD WEIGHTED COMMUTE SECONDS ON PATHWAY FOR ALL EXPOSURE CLASSES
DIVIDE PATHWAY COMMUTE SECONDS IN EACH CLASS BY TOTAL PATHWAY COMMUTE SECONDS
NEXT PATH
YES
MORE PATHS?
NO
ADD WEIGHTED NUMBER OF NETWORK COMMUTERS FOR ALL EXPOSURE CLASSES
DIVIDE NUMBER OF NETWORK COMMUTERS IN EACH CLASS BY TOTAL NETWORK COMMUTERS
ADD WEIGHTED NETWORK COMMUTE SECONDS FOR ALL EXPOSURE CLASSES
DIVIDE NETWORK COMMUTE SECONDS IN EACH CLASS BY TOTAL NETWORK COMMUTE SECONDS
DIVIDE AVERAGE NETWORK EXPOSURE SUM BY NUMBER OF PATHWAYS
END

FIGURE 21 FLOWCHART OF SUBROUTINE STATIS

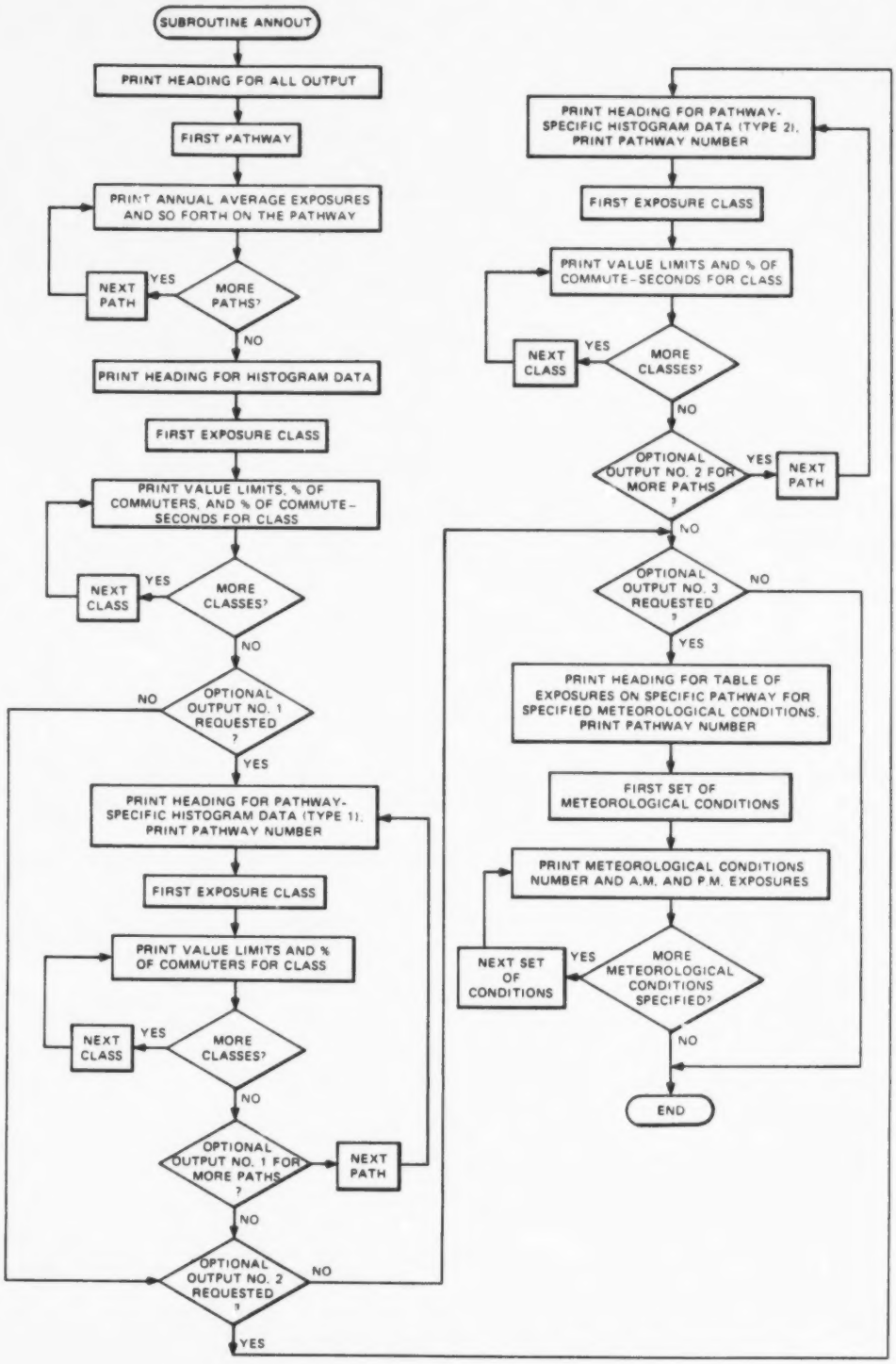


FIGURE 22 FLOWCHART OF SUBROUTINE ANNOUT

## SECTION 5

## ARRAY DIMENSIONS

To keep the core storage requirements of the commuter exposure model code within reasonable bounds, limitations were placed on the number of pathways, the number of segments per pathway, and the number of grid squares allowed by the model. Since many arrays are indexed by these variables, a small increase in the number of such parameters allowed results in a large increase in the amount of storage that is required.

It is recognized that some users with access to computers having a large amount of available core storage may want to increase the number of pathways, segments per pathway, and/or grid squares that can be treated by the model. To facilitate such changes, two tables have been included in this report.

Table 3 is a list of the common and dimension statements containing variables having pathway, segment, grid square, or pollutant as an index. In place of a number, an appropriate variable name appears in Table 3 in the array index position corresponding to that variable. Thus, the variable IPATH appears as an index in each array indexed by pathway number; currently, IPATH is set equal to 5 in the code. The segment number index is LINK, which is set to 20 in the code, and the grid square index is IGRID, which is set to 500 in the model. Finally, the pollutant type index is IP and it is set equal to 3 in the model. Table 4 is a matrix showing which common statements appear in which subroutines.

A note should be made regarding pollutant index, IP. If a user wishes to reduce the core storage requirments of the model, this may be

done by reducing the array dimension of IP. However, the model is set to operate with IP=2 (CO only) and numerous DO loops exist in the code of the type DO xxx IP=2,2. If the dimension of the array index IP is to be reduced from 3 to 2, the procedure is straight-forward; simply reduce the dimension. However, if the user wants to further reduce storage so that arrays are dimensioned for only one pollutant, all of the pollutant DO loops must be changed to: DO xxx IP=1,1.

A final note concerns alteration to the code that must be made if the dimensions of arrays having pathway number as an index are changed. Card type 2M reads the number of pathways and the number of segments per pathway, among other variables. The READ statement (statement 110 in subroutines INDATA) for card 2M reads the number of segments for 5 pathways, although the latter pathways may have zero segments if fewer than 5 pathways are being treated. If the dimension of the pathway index is increased, the READ statement and its associated FORMAT statement (number 111 in INDATA) must be changed to reflect the increased number of pathways.

Table 3

LIST OF COMMON AND DIMENSION STATEMENTS CONTAINING VARIABLES
DIMENSIONED BY PATHWAY, SEGMENT, GRID SQUARE, AND POLLUTANT NUMBER

```
 COMMON/TRAFIN/LINTYP(IPATH,LINK),IVSPRD(IPATH,LINK),LINTOP(IPATH,LINK),
1LINCAP(IPATH,LINK),NLANE(IPATH,LINK,2),LANWID(IPATH,LINK),IBOUND

 COMMON/DEFINE/LPATH,LNPATH,NPATHS,NSEG(IPATH),NGRID

 COMMON/PACOOR/X1(IPATH,LINK),X2(IPATH,LINK), Y1(IPATH,LINK), Y2(IPATH,LINK)

 COMMON/GRID/XG(IGRID),YG(IGRID),GVMT(IGRID),IGLOC(IGRID),GEMIS(IGRID),GSIZE(IGRID)

 COMMON/TRAFEM/TOTBAK(IPATH,LINK,2),DISBAK(IPATH,LINK,2),Q(IPATH,LINK,2),
1QDIST(IPATH,LINK,2),CYCL(IPATH,LINK,2),DEL(IPATH,LINK,2),P(IPATH,LINK,2)

 COMMON/TRAFOT/VOLHR(IPATH,LINK,4),LINSPD(IPATH,LINK,4)

 COMMON/TOLLS/TOLLS(IPATH,LINK,2)

 COMMON/BAKUP/VOLBAK(IPATH,LINK,2),CAPBAK(IPATH,LINK,2),
1BAKTIM(IPATH,LINK,2)

 COMMON/SIGNAL/R(4),GPH(IPATH,LINK,4),
1ACAP(IPATH,LINK,4),ADV(IPATH,LINK,4)

 COMMON/INFO/INTYPE(IPATH,LINK),INTDAT(IPATH,LINK),IVFORM(IPATH,LINK)

 COMMON/NOCOMM/NCOMM(IPATH,2)

 COMMON/TIMES/TT1(IPATH,LINK,2),TT2(IPATH,LINK,2),TOTTT(IPATH,2)

 COMMON/SAVE/EXP(IPATH, IP,2),COMSUM(10,IP,2),CMNSUM(10,PI,2),EINTVL(IP),
1EXPSUM(IP,2),AVCONC(IP,IPATH,2)

 COMMON/STRT/EXST(IPATH,IP,2)

 COMMON/NOPATH/EXNPAM(IPATH,5,IP),EXNPPM(IPATH,5,IP)

 COMMON/NOSTRT/EXNSAM(IPATH,80,IP),EXNSPM(IPATH,80,IP)

 COMMON/OPOUT/COMO1A(10,IP,5),COMO1P(10,IP,5),CMNO2A(10,IP,5),
1CMNO2P(10,IP,5),EXP3(10,IP,2)

 COMMON/LSTSEG/CNPLST(IPATH,IP)

 COMMON/PART/EXPP(IPATH,IP,2),EXPNP(IPATH,IP,2)
```

Table 3 (continued)

```
 COMMON/PAEMIS/ERATEA(IPATH,LINK,IP),ERATEP(IPATH,LINK,IP),W(IPATH,LINK)

 COMMON/EMSFAC/OUTFAC(2,11,IP),GRDFAC(2,5,IP),EMCR1(2,IP,6),
1EMAD1(2,IP,6),EMIDLE(IP)

 COMMON/GREMIS/EGRID(IGRID,IP,2)
```

From Subroutine INDATA

```
 DIMENSION AMPM(2),N4M(IPATH,LINK)
```

From Subroutine NPATHD

```
 DIMENSION CONST(5),JGRID1(IPATH,LINK),JGRID2(IPATH,LINK),JGRIDM(IPATH,LINK)
```

From Subroutine DISPRS

```
 DIMENSION C(2,80,IP),TT(2)
```

From Subroutine ROAD

```
 DIMENSION Y(6),WDIR(16),QE(2,IP),FAC2(2,IP),CON(2,IP),C(2,80,IP),AZ(5),
1AY1(5),AY2(5),WT(5)
```

From Subroutine SHORTY

```
 DIMENSION GREXP(IP),EXSQSM(IP)
```

From Subroutine STATES

```
 DIMENSION GREXP(IP),NWS3(10),NWD3(10),NSTAB3(10)
```

Table 4

SUBROUTINES IN WHICH EACH COMMON STATEMENT APPEARS

| COMMON Blocks | Subroutines | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CEMAP | TRAF | ART | FREE | MODE | EMISS | DISPRS | NPATHE | NPATHD | ROAD | STREET | SHORTY | STATIS | ANNOUT | GRAF | BLOCK DATA | INDATA |
| RUNTYP | X | X | X | X | X | X | X | X | X | X | X | | | | X | | X |
| TRAFEM | | X | X | X | X | X | | | | | | | | | | | X |
| DEFINE | X | X | X | X | X | X | X | X | X | | X | X | X | X | | | X |
| GENRL | | X | X | X | X | X | | | X | X | | | | | | | X |
| TRAFIN | | X | X | X | X | X | X | | | X | | | | | | | X |
| TRAFOT | | X | X | X | X | X | | | | | | | | | | | X |
| PACOOR | | X | X | X | X | X | | | X | X | | | | | | | X |
| SPREAD | | X | X | X | | | | | | | | | | | | X | X |
| INFO | | X | X | X | X | X | | | | | | | | | | | X |
| TIMES | | X | X | X | X | | X | X | X | | | X | X | X | | | |
| SECOND | | X | X | X | X | | | X | | | | | | | | | X |
| META | | | | | | | | | | X | | | X | | | X | X |
| TOLL | | X | | X | | | | | | | | | | | | | X |
| BAKUP | | X | | X | | | | | | | | | | | | | X |
| SIGNAL | | X | | | X | | | | | | | | | | | | X |
| IO | | | | | | | | | X | X | | X | | X | X | | X |
| PAEMIS | | | | | | X | | | | X | X | | | | | | X |
| GRID | | | | | | | | X | X | | | | | | | | X |
| METST | | | | | | | X | | X | X | X | | | | | | X |
| OPTION | | X | | | | | | | | | | | X | X | X | | X |
| EMSFAC | | | | | | X | | X | | | | | | | | | X |
| NOCOMM | | | | | | | | | | | | X | X | | | | X |
| OPOUT | | | | | | | | | | | | | X | X | X | | |
| SAVE | | | | | | | | | | | | X | X | X | X | | |
| LSTSEG | | | | | | | X | | X | | | X | | | | | |
| NOSTRT | | | | | | | X | | | | | X | X | | | | |
| STRT | | | | | | | X | | | | X | X | X | | | | |
| NOPATH | | | | | | | | | X | | | X | X | | | | |
| GREMIS | | | | | | | | X | X | | | | | | | | |
| PART | | | | | | | | | | | | | X | X | | | |

# SECTION 6

# PROGRAM LISTINGS

Listings of the computer code of the emission factor preprocessing program PREPRS, and the main part of the commuter exposure model, CEMAP, are included in the back of the report as microfiche. The microfiche contains listings for a UNIVAC compatible version.



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